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This study was performed in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

This report describes the development, design, operation and application of a large droplet, high intensity rainfall simulator. The apparatus generates 6.25 mm droplets and a 10 inch per hour rainstorm randomly dispersed to prevent drilling of the sample surfaces. An 8x12 foot array of generators is used to test a 4x8 foot sloped surface. The report also presents a recommended test method for evaluating erosion control products and media using the simulator. This method provides accelerated yet realistic erosion forces acting on a simulated highway slope.

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April 1980

FHWA No. F-5-15
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EROSION CONTROL PRODUCT TESTING USING RAINFALL SIMULATION

Study Made by .... Soil Mechanics and Pavement Branch

Under the Supervision of .... R. A. Forsyth and R. H. Prysock

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INTRODUCTION

Permanent protection of erodible soils disturbed by highway construction is customarily provided through vegetative cover. Great effort and expense have been put forth by both the private sector and governmental agencies to determine effective vegetation types and propagation methods for erosion-prevention on newly-constructed slopes. The propagation of grasses and shrubs for control of erosion in the long term is an integral part of the Caltrans maintenance program. However, soil loss, may be substantial during the interval between construction completion and vegetation establishment.

Most erosion control research has been conducted east of the Rocky Mountains, where markedly different weather patterns prevail than those experienced in the Western States. The West experiences similar large droplet high-intensity thunderstorm-type rainfall but does not receive the benefit of summer rains to promote early vegetation to protect the soil from such storms. This protection must be provided by temporary erosion control measures.

The short term erosion of earth disturbed during construction can be substantial. As a mitigative measure, contract specifications normally require that soils be protected during this interim period by application of mulches, meshes, spray-on chemicals, or other materials. These short term measures often are not effective. In many cases their inadequacies can be attributed to the use of unsuitable products, or the misapplication of products; i.e., a too-low application rate.

Federal and state legislation enacted in 1971, as well as executive orders relative to environmental pollution control, mandate that the pollution of established waterways as a result of construction activities be prevented. Compliance with this mandate requires extensive erosion control provisions in Caltrans contracts. These provisions include Section 7-1.01L "Water Pollution", of the California Standard Specifications, which states that the contractor shall submit an acceptable program for effective control of water pollution before commencing clearing or grubbing activities.

Caltrans has no test method or other rational basis for comparison of the numerous available short term erosion control products and techniques. This inability to compare treatments has made evaluation of a contractor's water pollution control program very difficult and has also hampered design of effective interim protection of newly constructed slopes.

Other researchers have utilized field trials to evaluate temporary counter-erosion media. Caltrans has conducted different independent field tests which have provided qualitative evaluations of products and techniques under specific field conditions. However, the results of these field trials are difficult to extrapolate for use at diverse project locations. Although Caltrans has used extrapolation of field tests as the basis for temporary erosion control treatment recommendations, such testing suffers from lack of control of exposure duration, storm intensity, storm frequency, and erosive capacity. Other disadvantages include very little control of surface disturbance hazards such as deer tracks and rodent burrows, or man's machines. Also, there is no assurance that after a season's exposure the products were in fact tested since lack of rain may result in no measurable erosion, even on untreated control plots. The various negative aspects of field testing of temporary erosion mitigants pointed up the need for a controlled laboratory test method that would model field rainstorm conditions to a reasonable degree.

Raindrop impact energy is an important factor in the erosion of new cut and fill slopes(1,8). Raindrop impacts detach soil particles from one another to initiate sheet erosion. As sheet erosion progresses, surface saturation occurs, and rill erosion begins. It should be noted that rill erosion due to raindrop impact and surface saturation is different from rill erosion as a result of overland flow of concentrated runoff, which is outside the scope of this project. In view of the impact detachment mechanism, erosion testing that would attempt to provide erosion through simulated rainfall should utilize large droplet (6+ mm) high-intensity (10 inches per hour) rainfall. Such rainfall also accelerates erosion rates, thus minimizing testing time. Simulated rainfall, while being of a high intensity with large droplets, should not introduce soil detachment forces in excess of those to be expected in nature, i.e., unnaturally large drops or excessive impact velocities.

Others have utilized artificial rainfall in various types of erosion research. Although at least one researcher has recognized the desirability of large droplet rainfall(23), there has been no reported use of large droplets in erosion research, possibly because production of large droplets is difficult. Reported simulated rainfall to date has been of small (2.8 to 3.0 mm) to moderate (4.5 to 5.0 mm) droplet sizes.

Caltrans embarked upon this research project with the following principal objectives: 1) to develop a simulator to produce large droplet high intensity rainfall; and 2) to develop a test method for evaluating temporary erosion control products using the simulator.

CONCLUSIONS AND RECOMMENDATIONS

The large stationary rainfall simulator developed during this project presents a potentially useful tool for the study of soil erosion.

The simulator has been highly effective in generating realistic erosion and erosion mechanisms at greatly accelerated rates. The same degree of erosion which may require months of field exposure can be induced in the laboratory in minutes.

The large droplet, 6.25 mm, free surface droplet formation system has proven completely successful. The droplet generators consistently provide large droplets at rates acceptable for generation of erosion on samples subjected to the rainfall. The rainfall generated is well distributed by the module system and its associated equipment. Although the air current system used to randomize the droplet points is considered adequate, it is felt that it could be improved with further study.

The test method evolved during this project appears to be suitable for evaluating erosion control products. However, more tests are needed to refine and support the work accomplished to date.

TransLab recommends that the test method developed through this project be used to develop acceptance criteria for most types of erosion control measures, including: fiber mulches, straw applications, plastic mulches, fibrous mats or blankets, and surface geometric considerations. After the development of acceptance criteria, this simulator should be used in conjunction with the test method to evaluate materials for application to California's slopes as erosion mitigation measures. The simulator should also be used to pursue other areas of erosion research.

IMPLEMENTATION

The rainfall simulator could be used in conjunction with the recommended test method to pursue the following investigations: 1) Develop acceptance criteria for the different generic types of short term erosion mitigants. 2) Using acceptance criteria developed, establish a list of acceptable products for temporary erosion control applications. 3) In addition, this facility should be used to evaluate both geometric and soil parameters as they apply to erosion mitigation.

The simulator can be used for other studies requiring simulated rainfall. For example, the simulator has already been used to evaluate the weather-tightness and serviceability of traffic controller cabinets when there was a question as to their acceptability.

Implementation of findings and recommendation should be by the Transportation Laboratory because of statewide application and the physical location of the rainfall simulator.

RAINFALL SIMULATOR DEVELOPMENT

The need for a large droplet rainfall simulator became evident during earlier studies which sought to evaluate various temporary erosion control products. This was confirmed by observations in 1972 in studies by Burgess Kay (unpublished) of the University of California, Davis. When he increased simulated rainfall intensity by increasing the number of drops without increasing their size, no significant changes in surface erosion were obtained.

Field observation indicates tnat high intensity storms are more erosive than low intensity storms. The additional erosive power can, therefore, be attributed to the larger droplet sizes associated with the high intensity storms. It was concluded that simulation of such erosive capacity requires large droplet high intensity rainfall.

Discussions with other researchers indicated that erosion initiated by 6+ mm droplet, 10 in/hr intensity, less than 10-minute duration storms is substantial in areas of California where this type of storm is typical. Such storms are common along the California central and south coasts, and in the thundershowers that occur in several mountain ranges of the state.

A further review of the literature suggested that much sheet erosion is initiated by raindrop impact. If raindrop impact is a prime initiating force, the larger the drop the greater the initiating force and the larger the particle that can be detached by the impact. With this background, studies were initiated to simulate large droplet rainfall. Such rainfall would have to be: 1) uniform in droplet size; 2) randomly distributed in its impact; and 3) relatively uniform in total coverage. These three characteristics are essential since, if simulated rainfall is not of uniform droplet size, it is very difficult to achieve any degree of repeatability with a testing program. Further, if rainfall is not randomly distributed, samples sustain drilling from the repeated impact of drops falling in the same place which does not occur naturally. In addition, if the rainfall is not relatively well distributed in total coverage, as well as being random, test repeatability cannot be achieved for large samples.

Three general types of rainfall simulators were evaluated for application in this project. The general groupings were: 1) the nozzle system, in which droplets are formed and flow is controlled by precision nozzles and pressure regulators; 2) the needle-droplet generator system, in which flow is controlled by surgical needles (or their equivalent), and droplet size is governed by the outside diameter of the needles or projecting tubing; and 3) the rotating disc simulator, in which nozzles are used to generate the droplets and a rotating disc controls the flow or volume of the water reaching the test sample. Each of these systems has advantages and disadvantages.

The nozzle system produces a somewhat random droplet size distribution. It has the capability for providing additional thrust to the droplets resulting in velocities greater than terminal velocity, as might occur with wind-driven rain. It also offers potential for portability. However, the droplet size regulation, a function of the nozzle design, pressure, and fluid temperature is extremely difficult. The pressure is also a flow regulator. Thus, flow control and droplet size are interdependent and cannot easily be separately controlled. Since large droplets require high flows, it is very difficult to generate a high percentage of large droplets and still maintain a low storm intensity while being able to generate other than a single fixed-type storm. A low intensity storm for laboratory purposes is six to ten inches per hour; which would be a natural storm of relatively high intensity.

The recently developed rotating disc simulator is a modification of the nozzle system consisting of a rotating slotted disc installed beneath the nozzle droplet generators. The disc controls the volume of water that reaches the sample. This system permits the generation of large droplets with the nozzles and provides for decreasing the droplet flow to the sample. Flow reduction is achieved by increasing the velocity of the disc. Those droplets that hit the disc and do not hit a slot are carried off by centrifugal force. Those droplets which hit entirely in a slot are passed through to the sample, while those hitting partially in a slot and partially on the disc are broken into smaller drops. Of the broken drops, part of the water is passed to the sample while the remainder is carried off. A disadvantage of this system, like the previous system, is the fact that the droplet size is not directly controlled. Thus, a high percentage of large diameter drops cannot be produced reliably.

The third system, the needle droplet generator (NDG), offered the possibility of independent flow control for each droplet-forming orifice and independent droplet size control for each droplet-forming surface. The NDG system had never previously been used to generate large diameter drops. The NDG system does not offer random drop size or impact distribution. Each droplet series comes through a nonmoving, single size, droplet generator. Thus, the drops must be distributed through some randomization process.

After evaluating the three types of rain simulation apparatus, the needle droplet generator system was chosen as the most likely to provide the desired large droplet controlled rainfall simulation and the three previously mentioned characteristics: large droplet uniform rainfall with a random distribution and a macroscopically uniform intensity.

Since the NDG system had not been previously used for large droplet generation and did not provide a mechanism for random droplet distribution, a study was begun seeking means to modify or adapt the system to the needs of this research. Initially, various methods of randomization were studied including rotational, translational or oscillatory motion of the generator system, and the introduction of air currents into the falling droplets to disperse them. Second, the area of droplet generation, in particular the generation of large sized droplets, was investigated. The critical parameters for large droplet generation are: 1) flow control, so that droplet flow rather than stream flow, is achieved, and 2) the outside diameter of the droplet-forming orifice, which actually controls the droplet size. With this knowledge, the droplet generator was selected and constructed from readily available, easily assembled components.

RAIN SIMULATOR COMPONENT DESIGN AND CONSTRUCTION

The rainfall simulator is a system composed of the following elements: the droplet generators; the modules that house the generators; a distribution system that conveys water to the modules from the head tank; and a head tank that provides water at constant pressure to the generators. Water filtration and flow-metering systems are used to provide repeatable flow and for rainfall intensity control. An air current affords random distribution for the raindrop impacts to prevent drilling, which results from repeated impacting of drops at the same point. Other components include a basic structure that supports and protects the simulator, sample boxes for soil containment and product applications, and a lift mechanism for control of the sample slope angle.

Droplet Generators

The droplet generators were designed to provide large (6.25 mm) diameter drops at low flow rates. In order to achieve this, two pieces of "Tygon" tubing were fitted together concentrically and inserted into a one-hole rubber stopper. The tubing consists of a short section of .01-inch ID by .03-inch OD inserted into a piece of .03-inch ID by .09-inch OD. This assembly is thrust into the small end of the rubber stopper (Number 00) with the .01-inch ID tube protruding (Figures 1 through 3). These generators were developed as individual units.

The "Tygon" tubing functions as a flow restrictor while the rubber stopper's large surface is used to control the droplet size produced. This system essentially produces a free surface droplet rather than an outside diameter formed droplet.

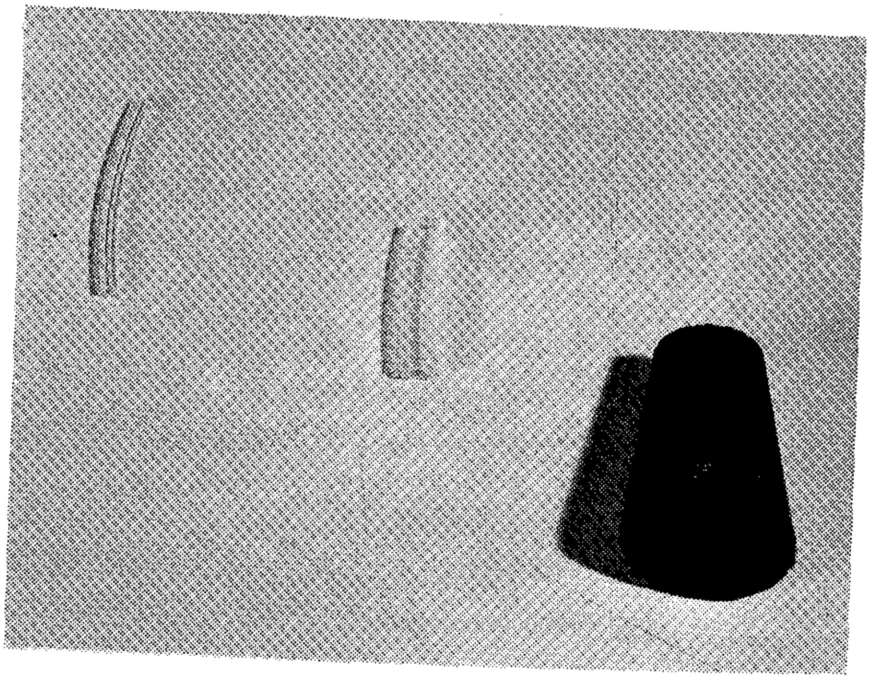


Figure 1 (above) Generator components.
(a) Tubing .01 in. ID by .03 in. OD,
(b) Tubing .03 in. ID by .09 in. OD,
(c) Rubber stopper, No. 00.

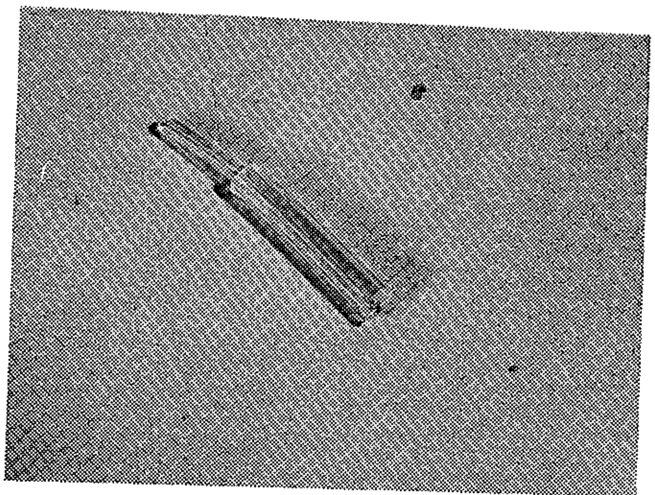


Figure 2 (above) Tubing sections fitted together.

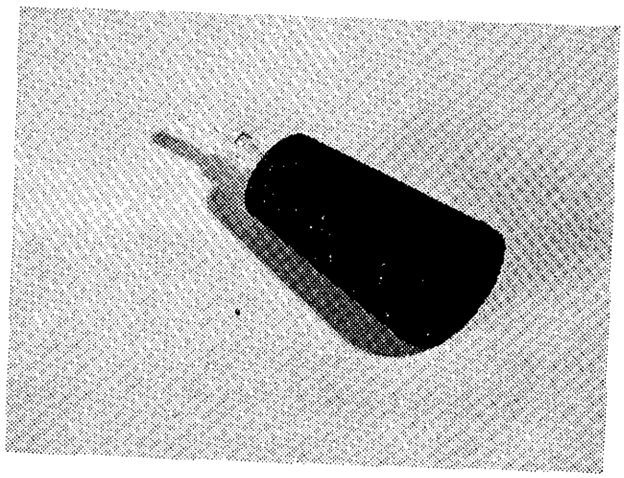


Figure 3 Complete assembly. Tubing mounted into stopper to form basic generator unit.

To provide actual rainfall simulation, these individual generators were assembled into a large array of evenly spaced, 1-1/2-inch center-to-center generators inserted into the bottoms of square acrylic modules (Figure 4).

Modules

The rainfall simulator modules, two feet square, are constructed of sheet acrylic with glued joints and have domed tops. The domes are fitted with valved vents in the peaks to permit evacuation of air entrapped in the box when filling takes place. Removal of entrapped air is essential to preclude compressible flow within the system. In addition to the air evacuation ports, the domed tops contain four inlet ports, centered in the quadrants as shown in Figures 4 and 5. These ports facilitate flow distribution to the 256 generators located on the bottom of the module. The inlet ports are positioned so as to prevent the inflowing water from impinging upon any underlying generator.

Twenty-four modules are assembled in an 8 by 12 foot array to provide a rather extensive rainfall pattern (Figures 5 through 7). The use of modules arranged in an array provides for more uniform flow distribution which results in a more uniform rainfall intensity throughout the test area.

As development and fabrication of the simulator progressed, it became apparent that the modules, as originally designed and constructed, were not capable of withstanding the stresses associated with expansion and contraction that results from ambient temperature fluctuation. Therefore, they were modified to increase their strength at the joints where the strains had produced separation of the seams. Machine screws

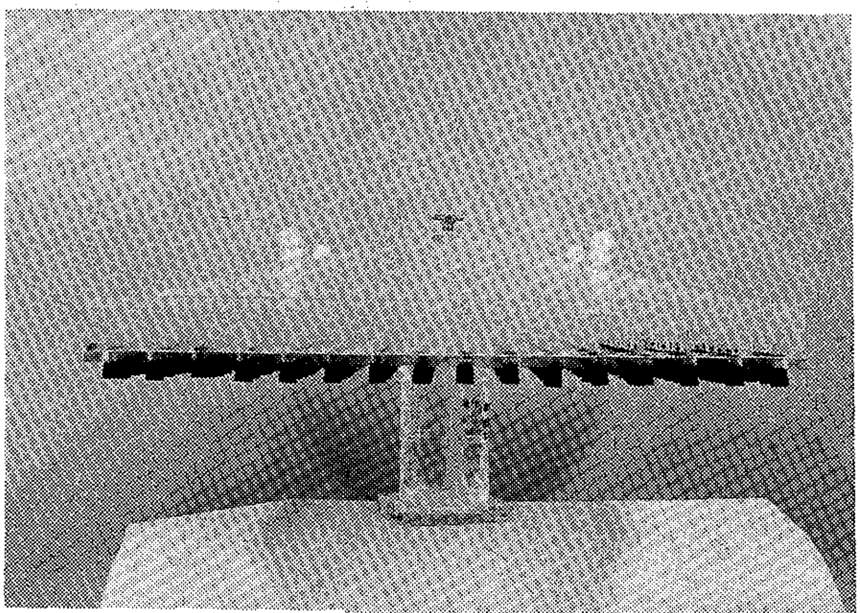


Figure 4. Module assembly. Note air vent atop domed cover.

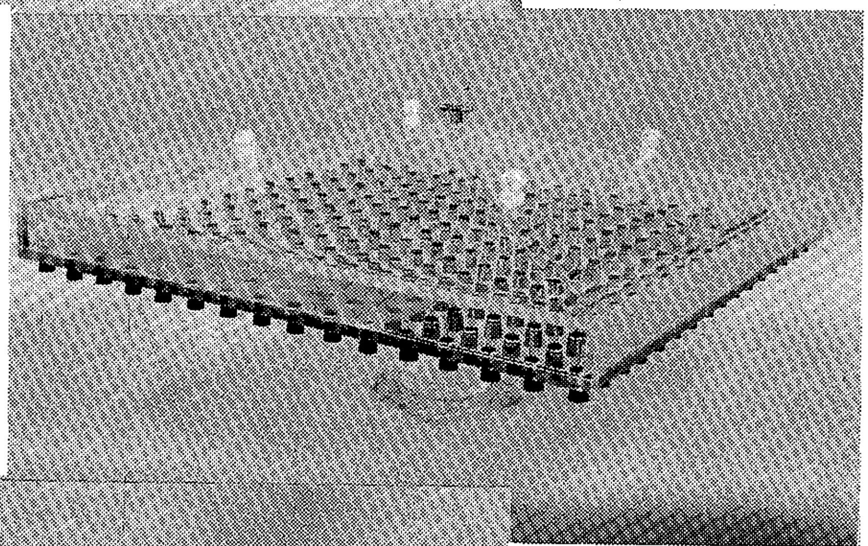


Figure 5. Module, viewed from above. The four white fittings are water inlet ports.

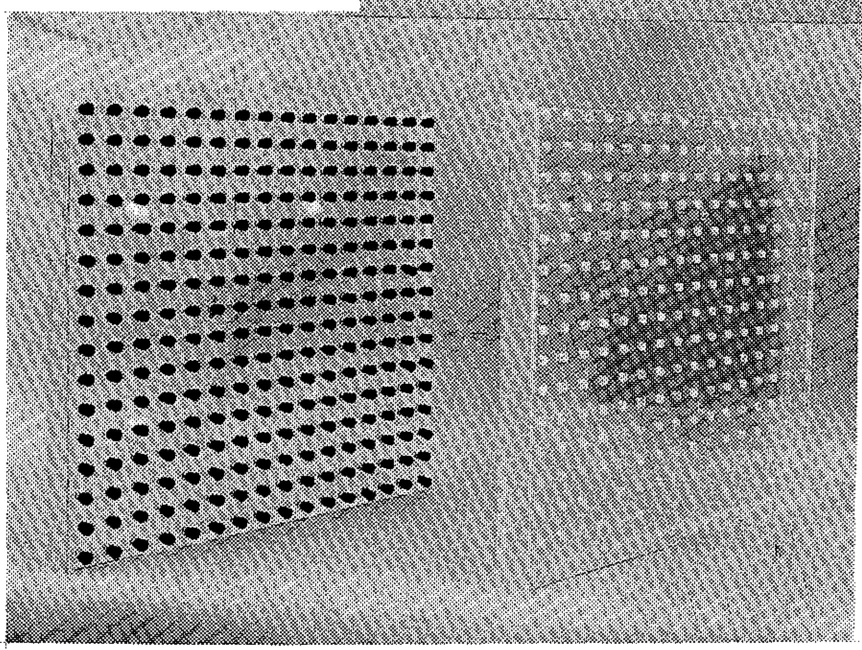


Figure 6. Module frames, before and after insertion of generators.

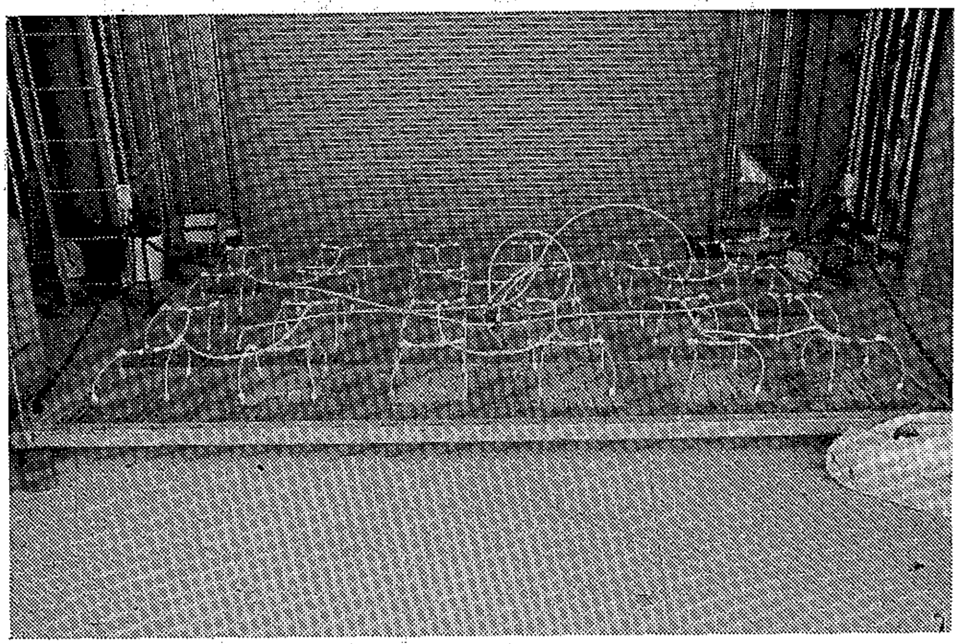


Figure 7. An 8 x 12 ft module array.

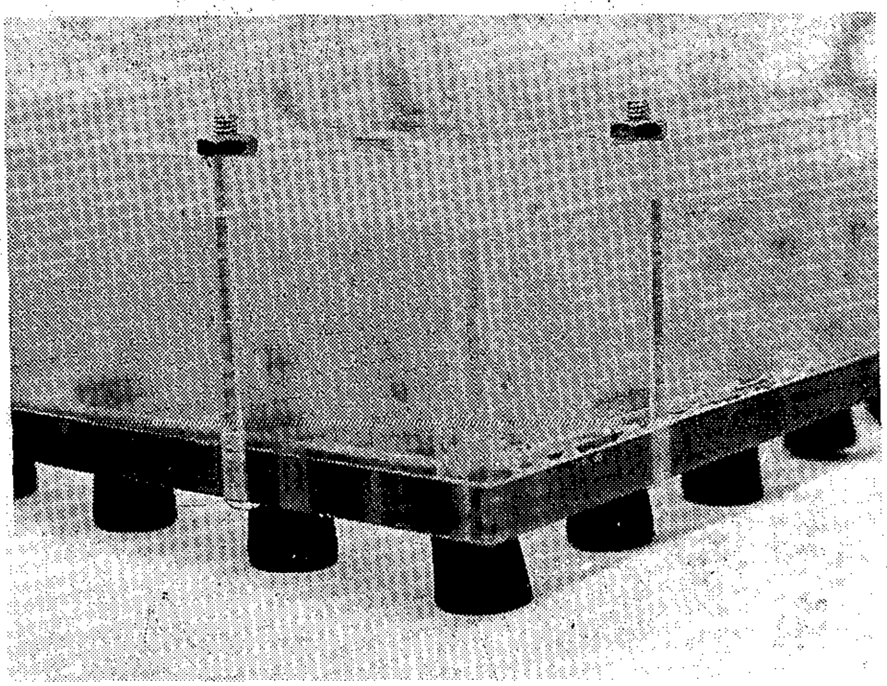


Figure 8. Module joints are strengthened with glue and machine screws.

were installed near the end points and at the center points along the module sides. The resulting compressive stresses provided sufficient increased strength to permit the acrylic glue to seal the leaking joints (Figure 8). Water is supplied to the modified boxes through a polyethylene manifolding system.

Water Manifolding

Flow distribution for the modules is provided by four inlet lines of 3/8-inch polyethylene tubing. These lines are joined by "T's", which are interconnected and hooked to a single 1/2-inch polyethylene tube, as shown in Figure 9. This 1/2-inch tube is used to connect two adjacent modules and again connected to a 1/2-inch tube, as shown in Figure 10. This pair of modules is hooked together with a second pair of modules through a "T" to form a group of four. Each group of four, as shown in Figure 11, is supplied by a 5/8-inch ID Tygon tubing line which is connected through a special connector system to the 1-1/2-inch supply line which comes from the head tank, Figure 12. The special connectors have a one-inch NPT inlet and three perpendicular 3/4-inch NPT outlets. The connectors, one-inch inlet pipes, are connected through a 1-1/2-inch "T" to the 1-1/2-inch supply line coming from the head tank. In this supply line is a strain gage flow meter suitable for measuring low velocity, low volume flows through a moderately large pipe, flow range 1.5-19.99 gpm.

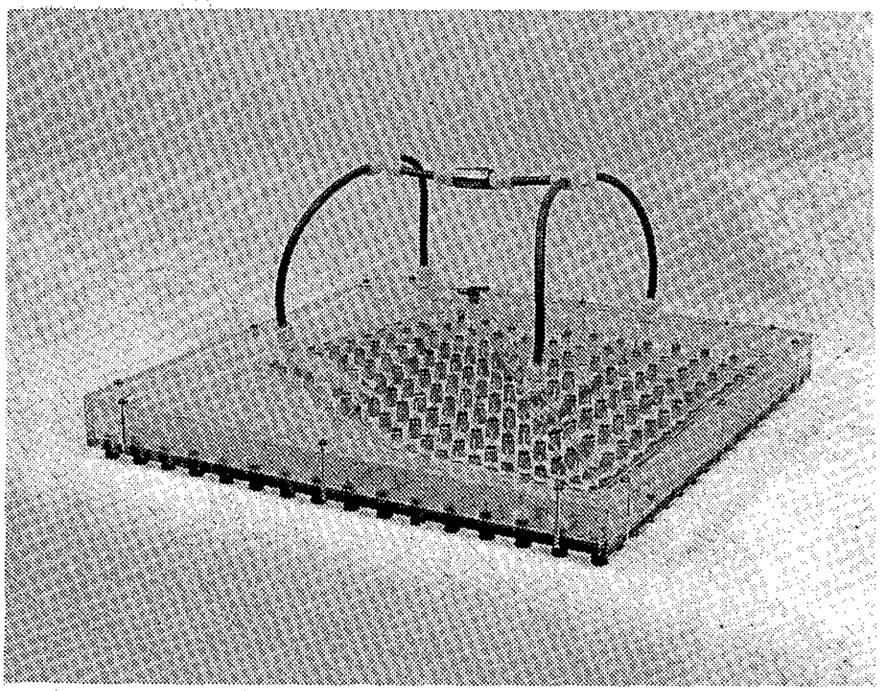


Figure 9. Tubing connections of a single module.

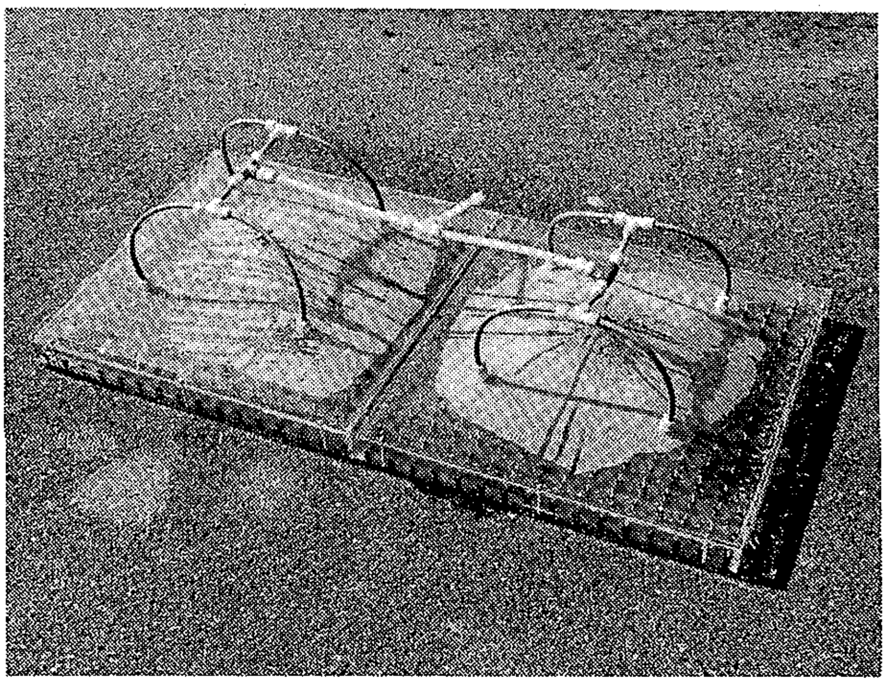


Figure 10. Two modules with connected tubing.

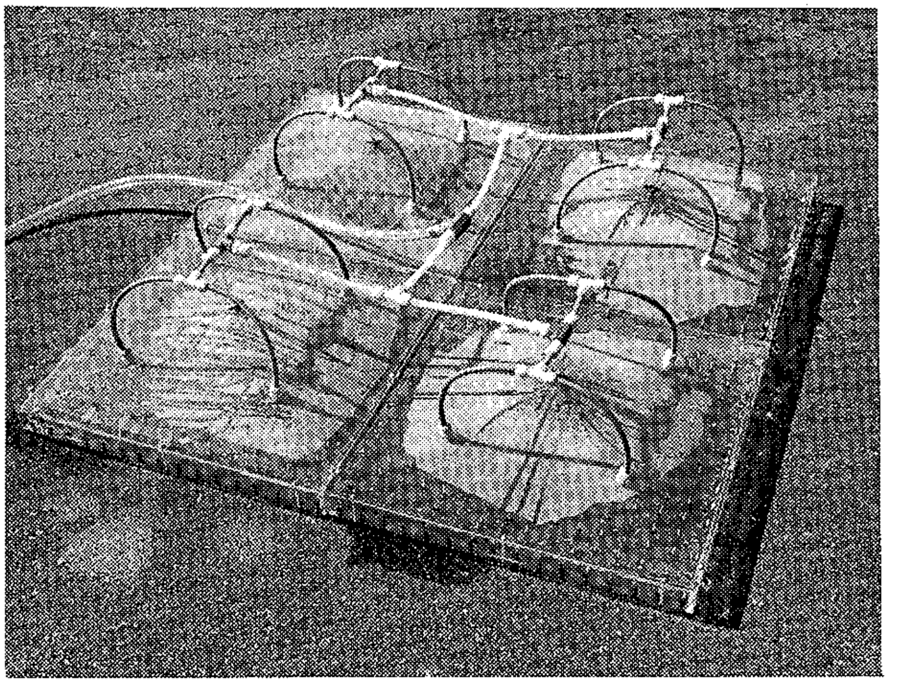


Figure 11. Four modules manifolded together.

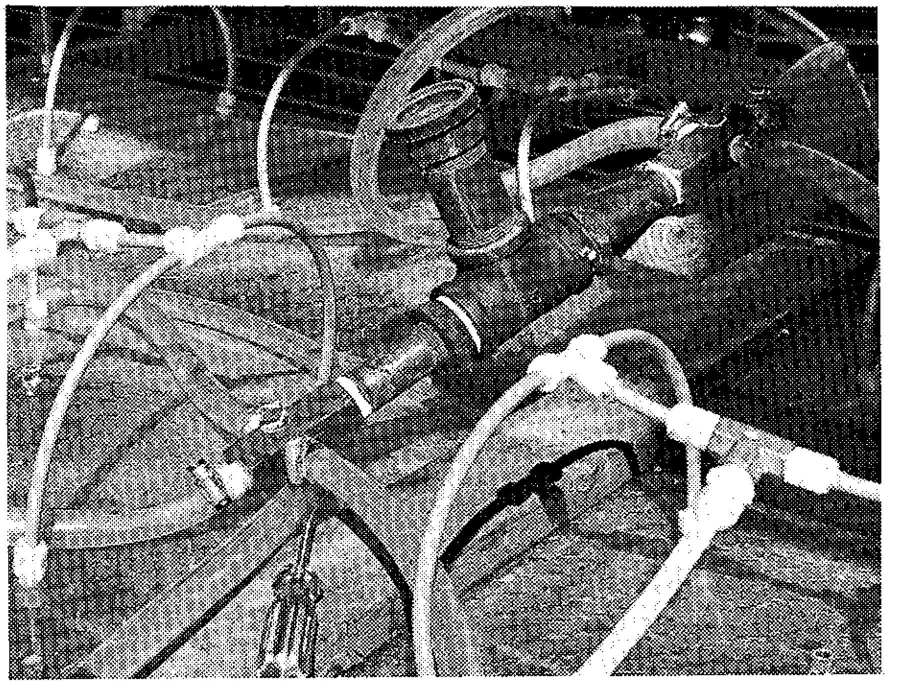


Figure 12. The connector between the 5/8 in. manifold lines and the 1-1/2 in. supply line.

Flow Meter

The flow meter is a target type, bonded strain gage bridge, with a ten to one flow range, and 0.15 of one percent repeatability. This meter was chosen for its repeatability and its ability to measure low flow and low velocity in moderately large pipes with low pressures. It is fabricated of stainless steel and utilizes a digital readout (Figure 13). This particular meter is designed for 1-1/2 to 15 gpm flows. For measurement outside of this range, however, the output characteristics are no longer linear, nor are they within the 0.15 percent repeatability.

Head Tank

The head tank, a teflon-lined, thirty gallon drum, is an overflow system of pressure regulation providing a constant head of 7.33 feet (Figure 14). This head was determined experimentally and represents the minimum that will provide sufficient flow to operate and fill the modules prior to testing. If the modules are not filled with water, the air remaining in them allows compressible flow which results in nonuniform rainfall distributions.

Water Supply

Water is supplied to the head tank through a one inch rigid plastic pipe. It is filtered through an AMF Cuno cartridge-type water filter, Model SS-2-HB, with Aqua-Pure cartridges (Figures 15 and 16). These cartridges (No. AP110) remove particles larger than five microns.

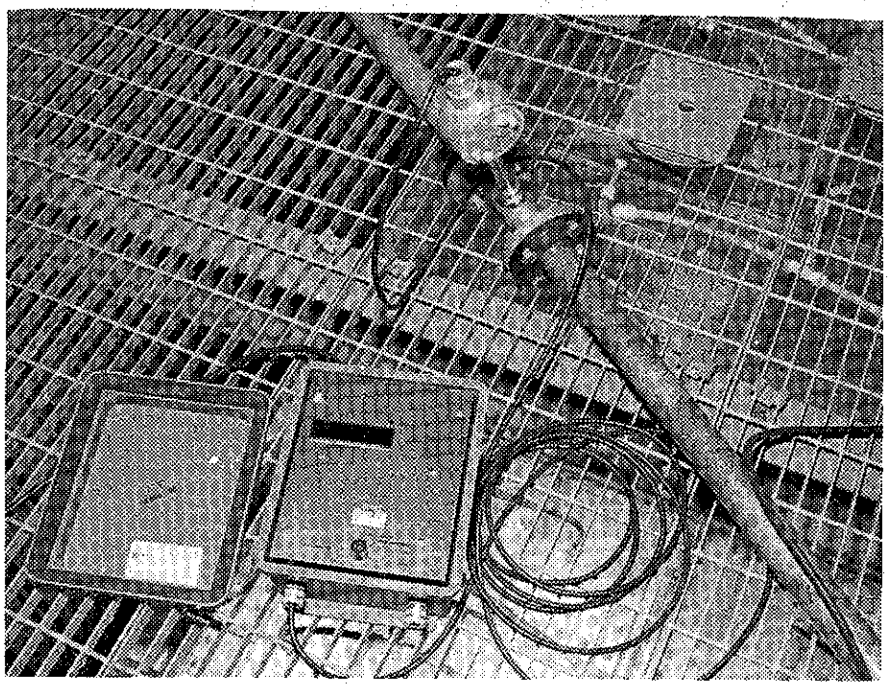


Figure 13. The strain gage flow meter (top) with digital readout.

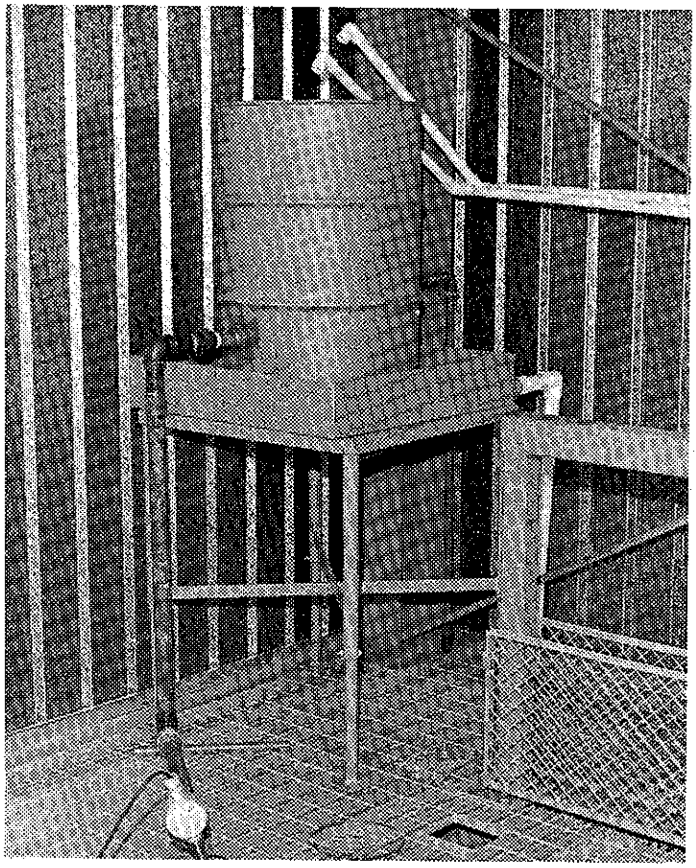
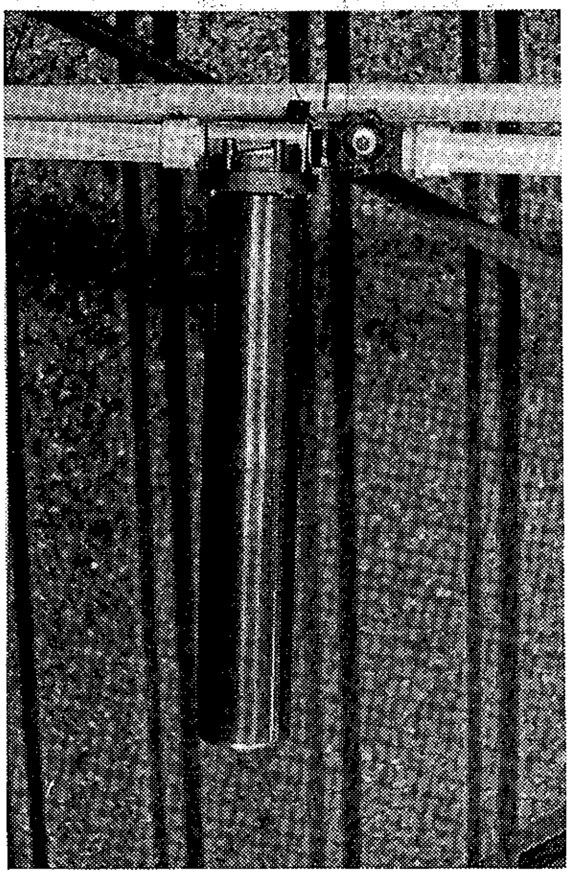


Figure 14. Head tank with overflow pan and supply line.



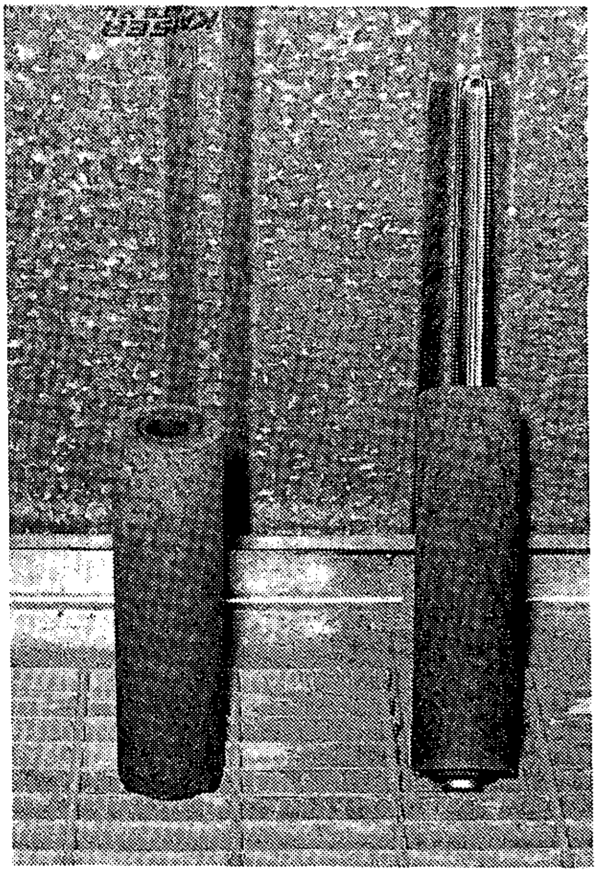


Figure 15. Stainless steel cartridge-type water filter.

Figure 16. Cartridges for water filter.

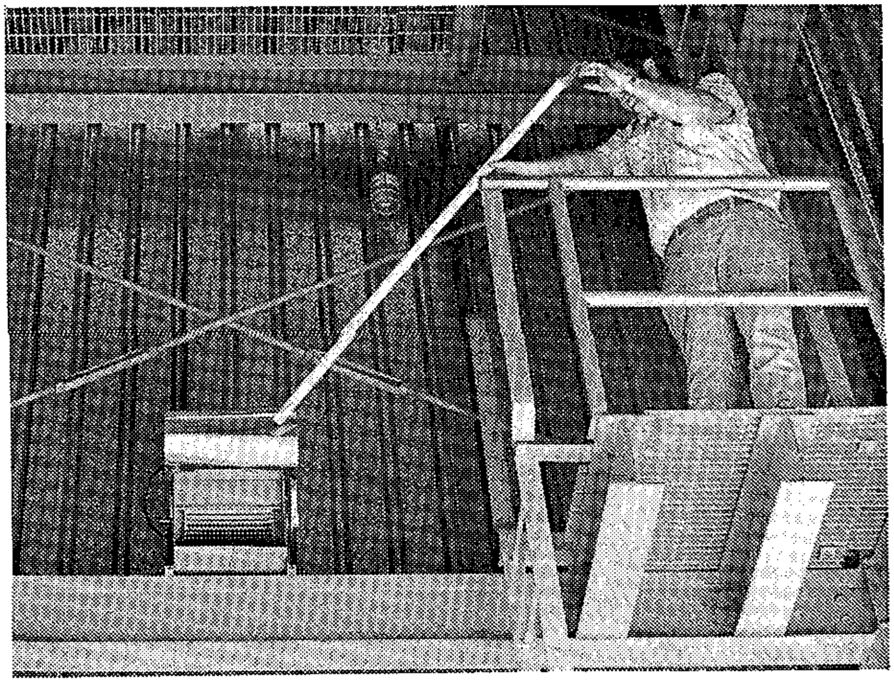


Figure 17. Blower for rainfall dispersion.

Raindrop Dispersion System

Complementing the water system is a droplet dispersion system. The uniform rainfall produced by the module array must be randomly distributed to eliminate the drilling effect which occurs when droplets are allowed to fall undisturbed from the generators.

The simulator dispersion is effected with a single blower unit that moves 2060 cubic feet of air per minute. The blower is approximately seven feet below the modules, on centerline of the 12-foot axis and three feet from the edge of the module's support frame (Figure 17). The air flow is inclined upward at approximately a 20-degree angle

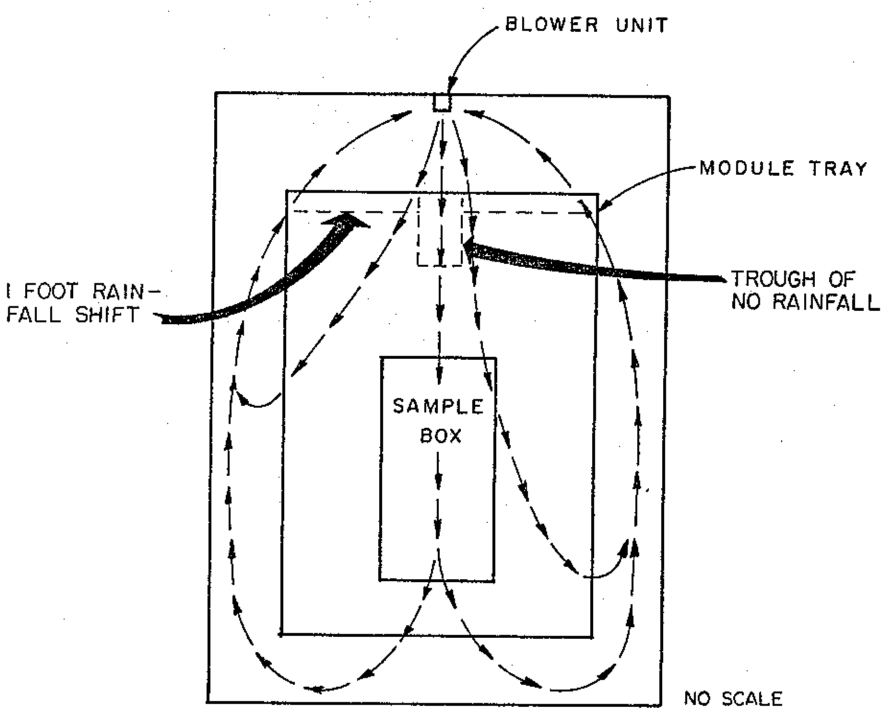


Figure 18. Pattern of air currents for droplet dispersion.

and is basically parallel to a vertical plane through the 12-foot axis, blowing from the upslope end of the soil sample. The return flow is back along the sides of the module support frame as well as over the top of the modules, thus yielding dispersion under the entire droplet generating array (Figure 18).

In addition to providing the required dispersion, the blower produces an overshift of the rainfall pattern. The droplet pattern is shifted approximately one foot from the original nondispersed contact area, in the downhill direction with respect to the sample. One aspect of this type of dispersion, considered a disadvantage, is the trough of no rain produced immediately in front of the blower. This trough is one foot wide and extends approximately three feet into the undispersed rainfall impact area (Figure 18). The trough must be considered when placement of the sample is determined. Taking into account the one foot overshift of rainfall, and the trough of no rainfall, this simulator still produces an 8 by 10-foot usable rainfall pattern.

Housing

All the components described heretofore are housed within a steel support structure designed by the California Department of Transportation, Office of Structures. The steel structure was chosen because of the speed of construction, its adaptability, and the lesser space requirements of steel versus concrete column construction.

The structure design was based upon a concentrated load near the top and the droplet fall distance required. This concentrated load was 5000 pounds, which approximated the weight of the component parts for the droplet generators, their allied distribution system, and the water contained within the system. The structure's height of approximately 35 feet required both wind loading and seismic loading design considerations with the large concentrated load near the top. Detailed design and construction plans are available from the California Department of Transportation. A group of photos depicting the simulator and its basic structural components during construction is presented as Appendix A.

Sample Containers

In addition to the rainfall simulation apparatus and support structure, an essential part of the test method research included the preparation of soil samples and the testing of various erosion control products for protection of the soils. In order to pursue this phase of the research, it was necessary to design and construct soil sample containment boxes.

The sample size selected was 4 by 8 feet. The choice of this size was influenced by field observations of erosion on compacted slopes, in which no erosion was observed in the topmost two to four feet. This suggested that a slope length in excess of four feet was required to initiate rill erosion. Taking into account the two to four feet necessary for erosion development and space to minimize edge effects, it was reasoned that an 8-foot sample length is about the minimum acceptable. The width was selected to provide adequate room for erosion without undue edge effects. The samples are one foot deep to facilitate compaction as thinner samples tend to break into lenses during compaction, resulting in unsuitable testing surfaces.

The boxes for containment of the soil samples are strongly constructed to provide rigidity when compacting samples and when handling the compacted samples. The boxes are fabricated with 1/2-inch thick steel plate and reinforced across the bottom on 12-inch centers with 3-inch I-beams. Banding around the top is also with 3-inch I-beams. The strength requirements were determined from previous experiences involving compaction of samples in large boxes. The boxes have removable endplates to facilitate dismantling and removal of a sample after testing (Figures 19 and 20). The sample boxes developed during this study provide adequate slope length for erosion development, enough rigidity for sample preparation, and acceptable handling characteristics.

Sample Slope Control

A lift mechanism was required to produce the desired test surface slope angle. The lift mechanism developed to control the slope angle of test samples is constructed from 3-inch I-beam longs, that run the full length of the sample and provide the box support, and a hydraulic scissor-lift system normally used for dump trucks (Figure 21). The system also includes mechanical props to provide constant inclination angle and safety during testing (Figure 21). It has a range of 0° to 65°, (horizontal to 1/2:1). The lift is designed to raise an 8,000 pound load from horizontal to the desired slope angle.

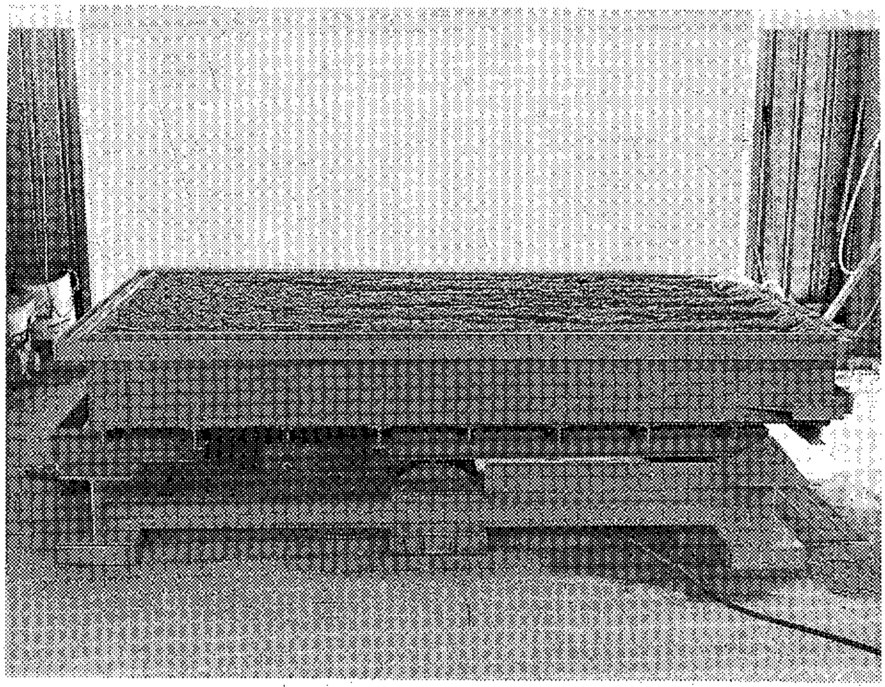


Figure 19. Sample box. Note banding along top edge and "I" beam reinforcement of the bottom.

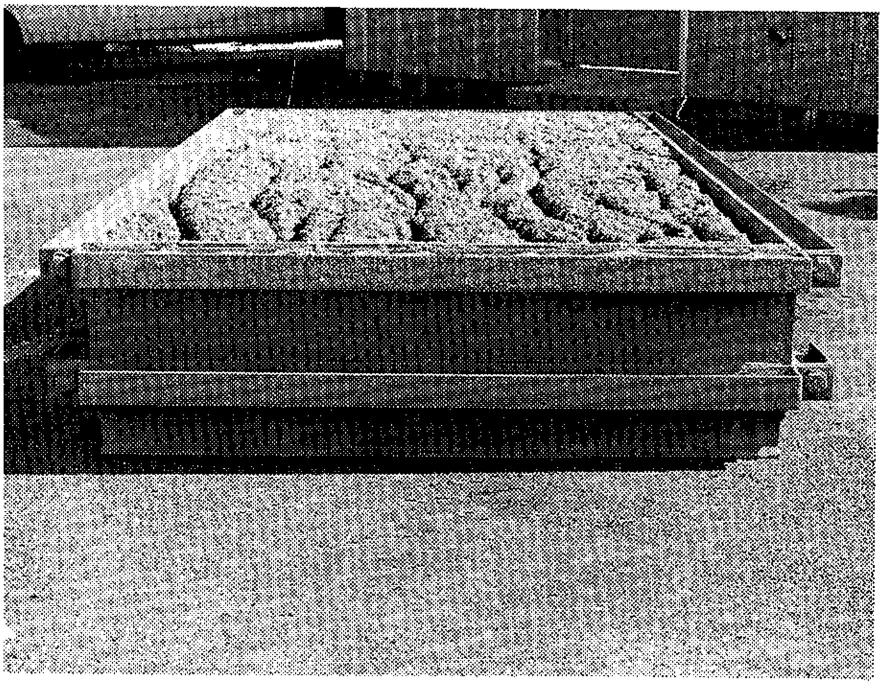


Figure 20. Removable endplate of the sample box, held in place by 4 bolts.

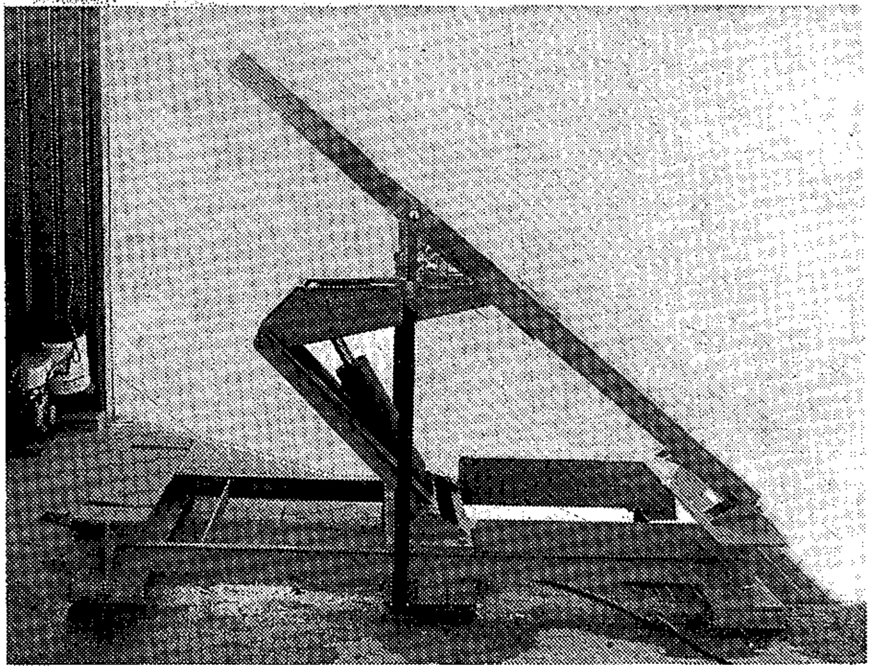


Figure 21. Sample lift mechanism, showing scissors type lift and safety prop supports.

Construction Costs and Present Worth

This facility was constructed in two simultaneous phases. The structure was contracted to a private firm through normal Caltrans contracting procedures. The plans and specifications for the contract were prepared by the Caltrans Office of Structures. Bids for the structure based upon the plans and specifications provided ranged from a high of $108,000 to $64,470, the accepted price. The simulator housing structure was erected concurrently with the fabrication of the internal appurtenances. The modules were fabricated by the TransLab's Machine Shop as were the lift mechanism and sample boxes. The module fabrication and assembly cost $17,000, while the sample containers and lift were fabricated for $6,000. Other miscellaneous features, including the flow meter and manifolding system, the air current distribution system, catch basin and sample lighting, brought the total cost of this facility to $109,000.

The cost to replace this facility in June of 1980 is estimated to be approximately $124,000, even though the initial construction cost was only $109,000. This increase in cost is due primarily to inflation. These replacement costs include the rainfall-generating equipment, the housing, sample boxes, lift mechanism, and other components previously mentioned.

SIMULATOR OPERATIONS

Operation of this facility involves supplying the water to the modules, venting and closing the modules for noncompressible flow and then adjusting the inflow rate to obtain the desired rainfall rate. Before sample testing begins the blower must be turned on to provide droplet dispersion. After turning on the blower, it is necessary to wait for a period of 1 to 3 minutes for the turbulent air dispersion system to stabilize.

Simulated Rainfall Characteristics

The rainfall produced is large-droplet, 6.25 mm, at 90% of terminal velocity. The rainfall intensity afforded ranges from 6 to 12 inches per hour. At this writing, a rainfall intensity of 10 inches per hour is being used for testing purposes. Observation of samples indicated no drilling effects when the integrity of the enclosure is maintained. However, if any venting is permitted, the turbulent air dispersion system no longer functions properly and drilling does occur.

Due to the air current dispersion technique, some nonuniformity of rainfall occurs. Rainfall measurements within the testing area show that when samples are taken for a 6 to 30 minute collection period the variation is less than five percent; that is, the samples are all within five percent of the mean rainfall value for all samples that have the same time of collection and the same flow rate. Measurements for sample periods of less than 6 minutes duration were inconsistent. No measurements were made for sample periods greater than 30 minutes.

Simulator Operation Procedures

The following step-by-step procedure is currently employed:

1. Turn on the water supply valve to permit inflow of filtered water to the head tank.

2. When the head tank overflows, turn on the modules.

3. Adjust the flow into the modules to from 16 to 17 gallons per minute. The head tank should still be overflowing.

4. Open all module air vents in the domed sections of the tops to permit air to escape. This eliminates compressible flow.

5. As modules fill, close the vents. A slight vacuum applied to the vents will accelerate filling, and more thoroughly remove the air. When the water temperature exceeds 60 degrees Fahrenheit the vacuum may be necessary to fill some modules, since the water's viscosity will decrease enough to flow through the generators without filling the modules. (Make sure all module vents are closed.)

6. When all modules are full, adjust the flow control valve to the flow rate for the rainfall rate desired. (One gallon per minute equals a rainfall rate of 1 inch per hour.)

7. Adjust the water flow into the head tank to only a slight overflow, to minimize waste of water while still providing a constant pressure head. The quantity of overflow should be sufficient to insure constant head even with incoming line variations.

8. Turn on the blower for droplet dispersion.

9. Wait 1 to 3 minutes for the system to stabilize and achieve the uniform air turbulence pattern that provides droplet dispersion. The time interval from initial turning on of the water until the simulator is producing uniform, dispersed, steady-state rainfall is approximately 1 hour.

10. Uncover the sample for testing.

11. Record exposure time to first rilling.

12. After completion of the test, the cover is replaced over the sample to protect it until it can be removed, or the simulator drained. Draining the simulator takes two to three hours and requires opening of the module vents.

TESTING PROCEDURE

The test method investigation was based on experience with erosion control testing in the field, other researcher's experiences, and a review of the literature. The test slope angle, for instance, was based on the fact that many of California's highway slopes in erodible material are constructed at a 1-1/2:1 slope angle, and the indication by other researchers that the critical slope angle for initiating erosion is 1-1/4:1. The difference in erodibility between 1-1/4:1 and 1-1/2:1 slopes is slight. Therefore, the slope angle most common in California, 1-1/2:1, was selected for the test slopes.

The soil chosen to develop the test method was angular noncohesive decomposed granite, a grading of which is shown in Figure 22. It has a specific gravity of 2.72 with less than 1 percent organic material. This highly erodible soil is readily available to the laboratory and found in considerable extent at various locations in California. This soil type is especially prevalent in the mountainous areas where constructed slopes are likely to be erodible.

The 10 inches per hour test rainfall rate selected represents a realistic maximum intensity for storms in California, as previously discussed, and will provide an accelerated test for erosion, a goal of the testing.

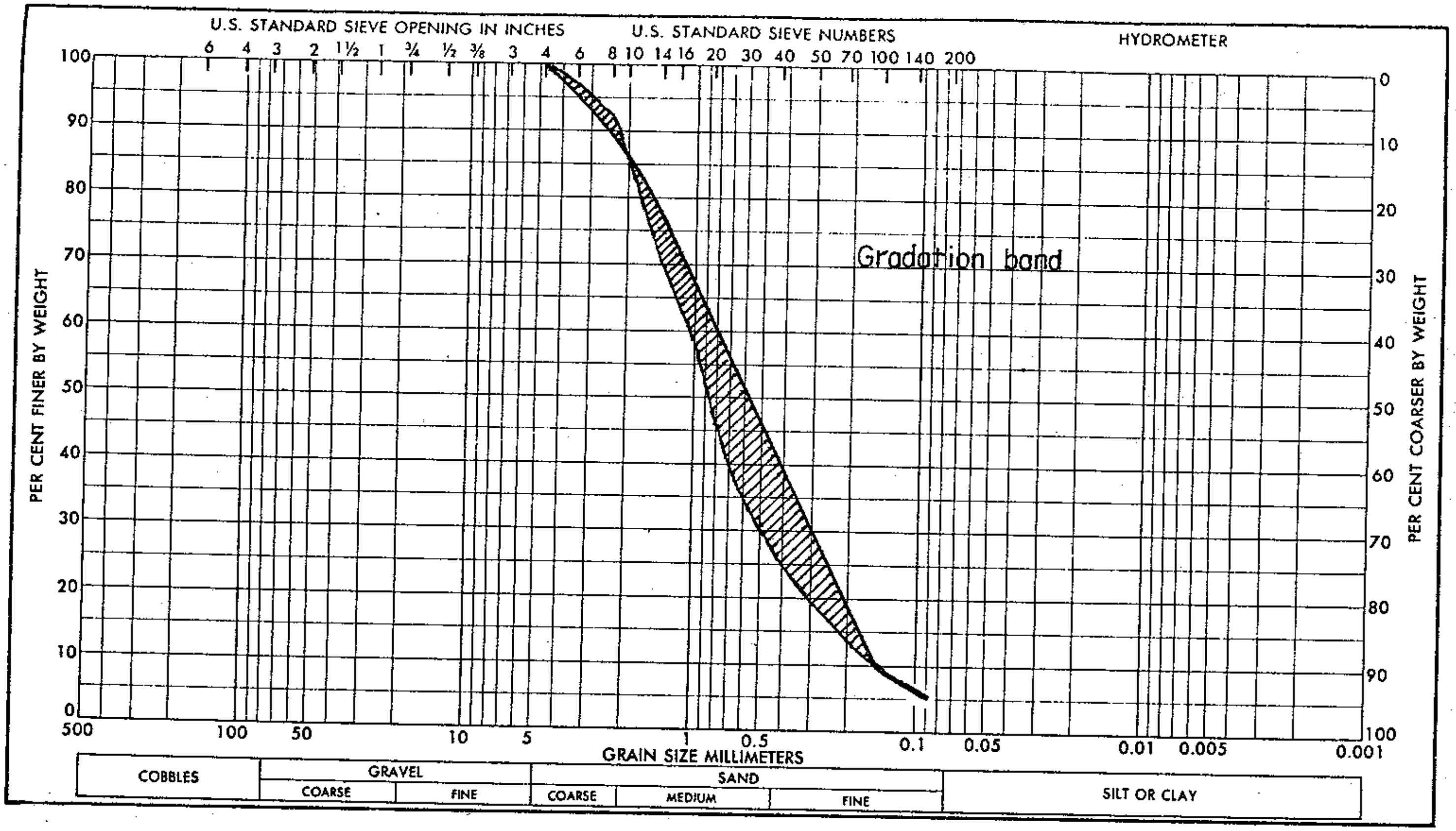


FIG. 22 GRAIN SIZE ANALYSIS OF TEST SOIL

Treatment rates for various products were determined by the researcher's field experience. It was felt that if the rate used was similar to one that has proved effective in the field, the comparisons of various products to each other and to an untreated slope would be more meaningful than if an arbitrary rate were used only for product comparisons. While these rates may not be used in the recommended test method, they facilitated the method development.

The testing procedure involves sample preparation, sample exposure and evaluation, and consideration of acceptance criteria. Acceptance criteria were not determined during this project due to its limited scope. More testing would be required to determine viable acceptance criteria.

Sample Preparation - Compaction

Preparation of a soil sample for testing requires that it be compacted in the sample box using a pneumatic compactor, in 4-inch lifts, to a given test density. The compacted test density is measured after the sample is prepared, by a nuclear gauge utilizing the back-scatter mode. The back-scatter mode minimizes sample surface disturbance while obtaining near surface densities. As erosion takes place at the soil surface, density at depth generally is not of particular interest. Following compaction and density evaluation, the sample is allowed to "season" before being treated with any erosion control product which reflects standard procedures currently employed in field applications. The seasoning time will be discussed in detail in a subsequent section of this report.

Sample Treatment

Tests to date indicate that treating one-half of the four-foot width, while leaving the other half untreated, is the most suitable way of evaluating the benefit of treatment versus no treatment when using fiber mulches and other similar treatments. Such treatments as the spray-on plastic mulches should be tested over the entire sample surface because their durability is much greater than a nontreated surface. When comparing two different products of the same generic type, each half of the soil sample would receive a different product; thus testing them in comparison to each other, not to an untreated sample.

After treatment is applied, the samples are again allowed to season prior to testing. The seasoning process takes place out-of-doors to simulate field conditions. Samples treated and cured indoors do not necessarily yield results comparable to samples cured out-of-doors.

The soil samples are seasoned before and after treatment to simulate the field application procedure and to allow the products to cure. This testing program indicated that the length of seasoning periods must be uniform to achieve repeatable results. Furthermore, longer seasoning times result in increased durability of the samples, both treated and untreated. Based on preliminary findings and the time required for testing, seasoning periods selected were one day for the untreated surface, and three days for the treated surface. A three-day seasoning period for the treated surface facilitates treatment on Friday and testing on Monday. "Untreated" samples should be seasoned one day, lightly sprayed with water (which simulates the treatment stage), then allowed to season another three days. The water spraying is used to simulate the action of treating a sample with a mitigant. The treatment action, alone, is of some benefit in resisting erosion. Product evaluation should consider the product benefit alone rather than the benefit attributable to the treatment action.

During this project, both wood fiber mulches and the spray-on plastic mulches were utilized. The wood fiber mulches were applied at a rate of one ton per acre, while the spray-on plastics were used at a rate of 1000 pounds of solids per acre. Such rates are currently being used in California for field applications of erosion control products.

The wood fiber mulch was applied with a 20 litre hydromulcher manufactured by the Reinco Company, while the plastics were applied through a garden-type compressed air sprayer set to provide a droplet spray. The droplet-type spray was chosen to simulate the field application spray.

Sample Exposure

After a sample has been compacted, treated, and seasoned it is ready for testing. It is covered with a rigid, clear sheet acrylic cover, placed on the lift mechanism, raised to the desired angle, and propped up with the constant angle safety supports. The test involves exposing the surface to a 10-inch per hour storm while inclined at an angle of 33.7 degrees (1-1/2:1). Once the cover is removed, the sample condition and time of exposure are monitored until failure occurs. When the sample shows its first sign of rilling, it is deemed to have failed. It is then covered again with the sheet acrylic cover, lowered to a horizontal position, and removed from the test area.

Experience with this facility has shown that irreparable failure is only a matter of time once the first signs of rilling appear. It is, therefore, much simpler and realistic to utilize initial rilling as the test criteria rather than some later degree of rilling or volume of soil loss. The rationale for this criteria will be discussed in detail in the following section.

Sample Evaluation

Various methods of sample evaluation for erosion resistance were investigated. As experience was gained with the rainfall simulator, it became apparent that most quantitative methods were too time-consuming and cumbersome to be practical. The evaluation method used had to be applied to the sample while it was being tested to determine if sufficient exposure was achieved. A test method in which the time of exposure is predetermined would lend itself to a quantitative evaluation technique such as cross-sectioning of the sample before and after exposure to determine soil loss. This type of test, however, is only an indirect evaluation of the protection provided by the treatment since soil loss is dependent upon more than just the treatment and treatment technique. The less quantitative method chosen in this project; i.e., the appearance of the first rill deemed to be failure with the time of exposure until this occurs as the recorded parameter, is a more direct evaluation of the protection afforded by any given treatment and treatment technique. Thus the samples are evaluated during exposure, not for acceptance or rejection, but only for time of protection. This time of protection is then compared to that of an untreated sample of the same soil type and density as well as seasoning times. It is this comparison that yields the final evaluation of a product in terms of acceptance or rejection.

Testing with the wood fiber indicates that the fiber provides sufficient protection for the sample to be exposed to the simulated rainfall for approximately twice the time that an untreated sample can be exposed without rill initiation.

The spray-on plastic mulches that have a proven history of success in field applications increase the time of exposure without rilling to approximately 5 times that of an untreated sample. The plastics known to be unacceptable increase the exposure time to only 3-1/2 times the untreated sample exposure time to rilling (Figures 23 through 26).

Testing to date also indicates a general tendency for increased surface compaction to inhibit the effectiveness of the surface erosion treatments. The results of this study did not indicate any acceptable correlations between density and exposure durability nor were any other parameters determined which would correlate directly with sample durability. Variables that influence the durability of erosion treatments are highly interdependent.

RECOMMENDED TEST METHOD

The test method developed during this project is based on limited testing and may require revision as more data are obtained. The procedure is:

1. Compact a noncohesive soil (100% passing a Number 4 U.S. Standard sieve and less than 10% passing Number 200 U.S. Standard sieve) to a density of (87 to 91%) of its maximum as measured by California Test 216. The soil should be compacted with a pneumatic compactor in 4-inch lifts, in a one-foot deep sample container. The sample should be 8 feet long and 4 feet wide. The compacted sample is then finished to a smooth surface by striking off.

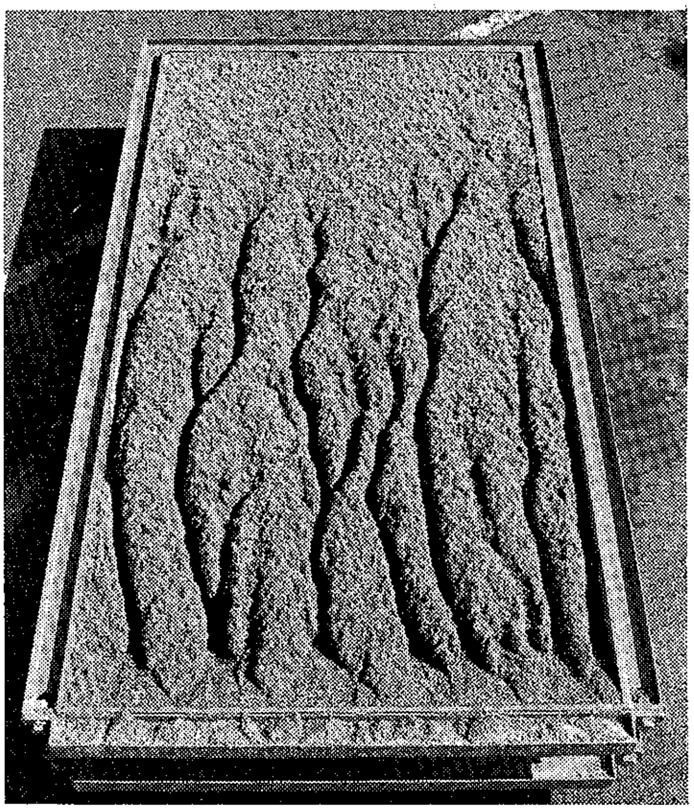


Figure 23. An untreated sample eroded beyond repair after 8 minutes exposure.

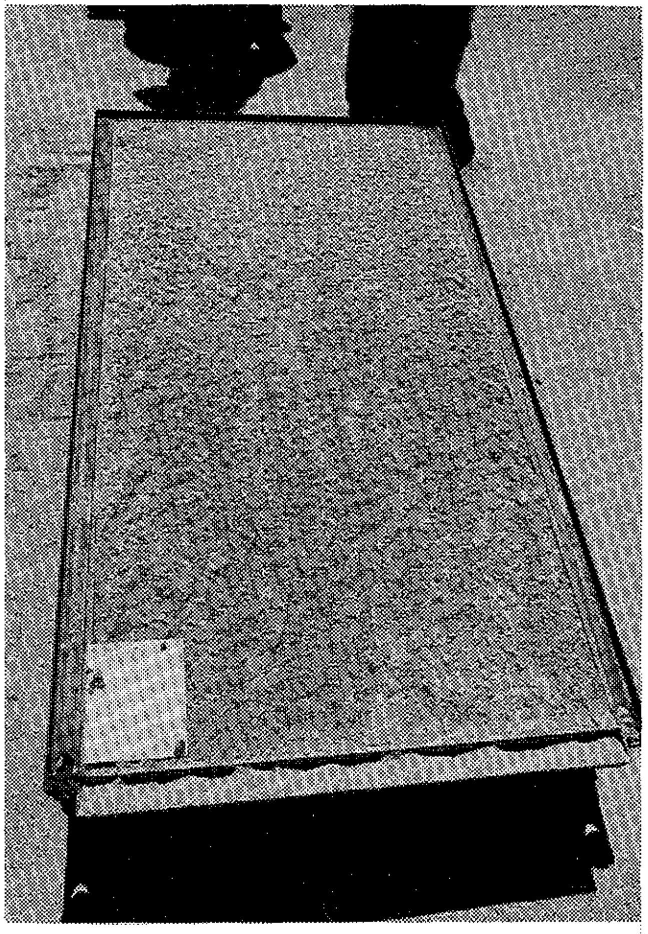


Figure 24. A wood fiber protected sample after 6 minutes of exposure.

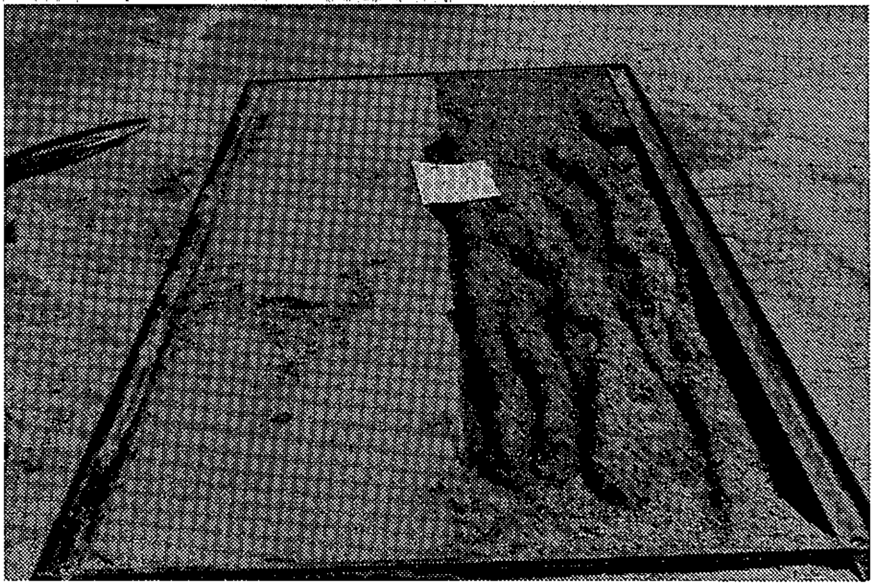


Figure 25. Left side was treated with a spray-on plastic; right side was untreated. Exposure time: 14 minutes.

Figure 26. Right side was treated with a spray-on plastic; left side was untreated. Exposure time: 12 minutes.

2. Measure the density with a nuclear gauge in the back-scatter mode. If the density is not in the acceptable 87-91% range, reconstruction of the sample is required.

3. Season the sample for one day.

4. Apply the erosion control product; either per manufacturer's recommendations or other specifications.

5. Allow a three-day seasoning period.

6. Submit the treated sample to the 10-inch per hour simulated rainstorm, as previously described.

7. Visually monitor the sample for rilling.

8. Record the time of exposure when the first rill appears.

9. Determine the protection time.

10. Determine the erosion protection ratio (EPR) by dividing the protection time by the endurance time of an untreated sample. (The endurance time for an untreated sample is its exposure time to first rill.)

The EPR provides a convenient means for accepting or rejecting products. No acceptance criteria were determined through this limited testing program.

It is suggested that any product be tested at least twice. If the product is of the fiber mulch type, alternate sides of the 4-foot sample width should be treated in 2-foot widths.

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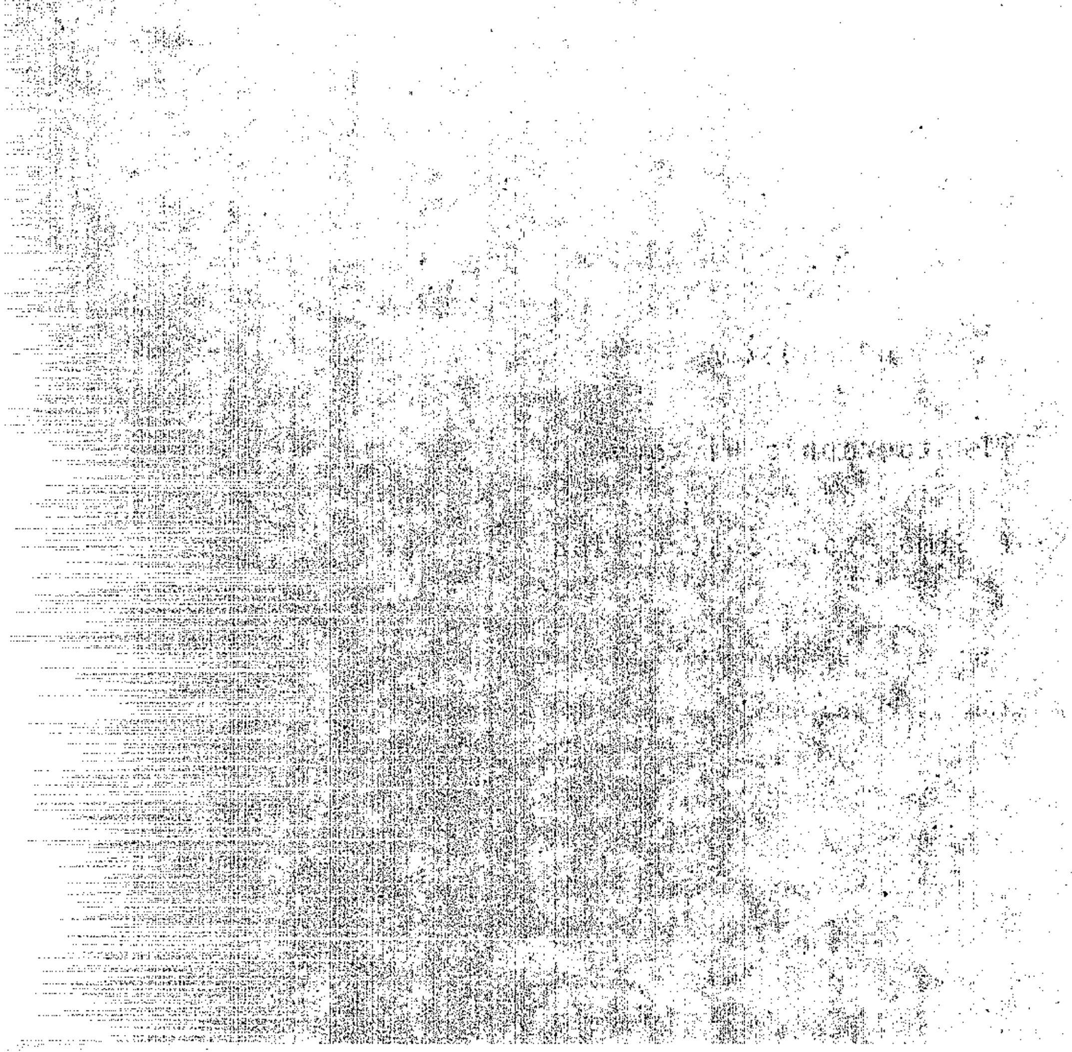
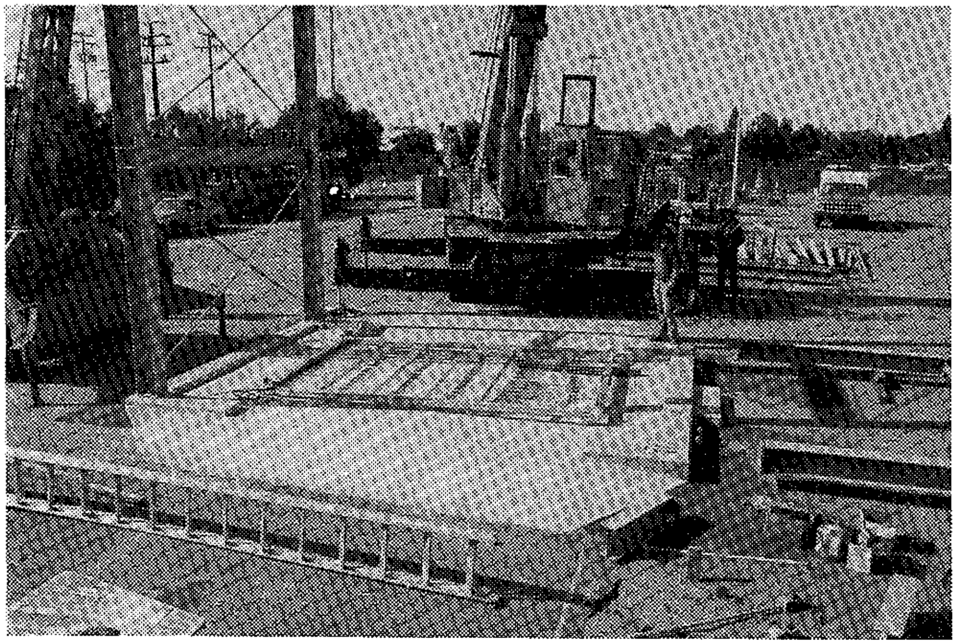
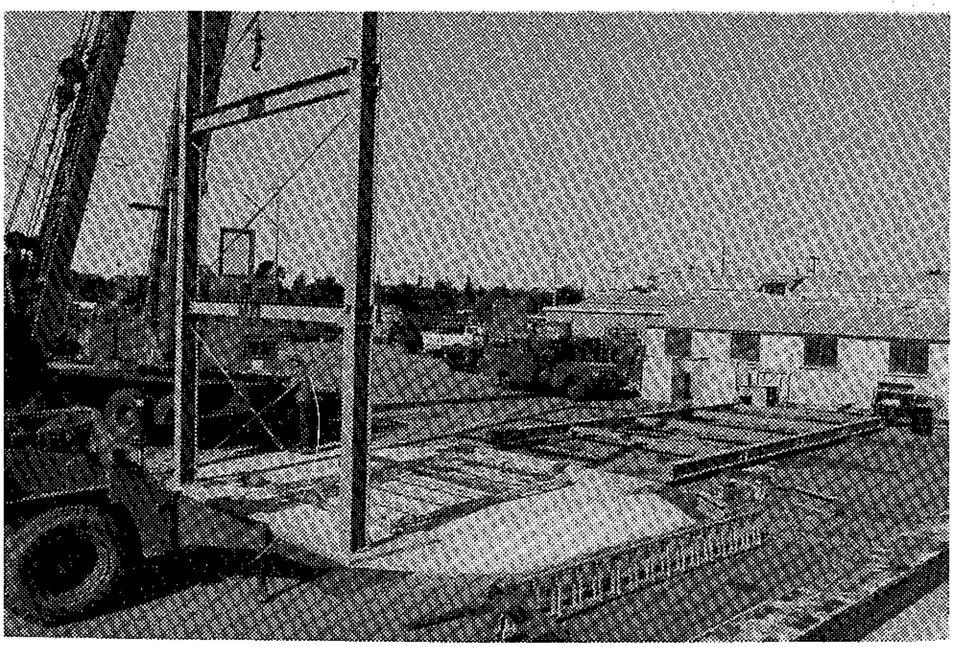
APPENDIX A

Photographic History
of the
Rain Simulator Construction

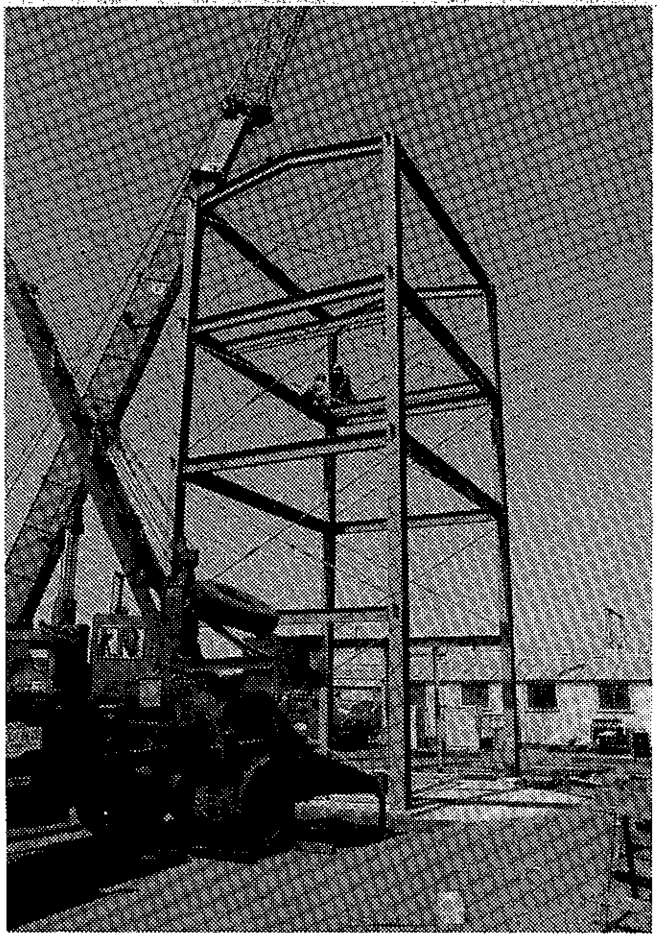




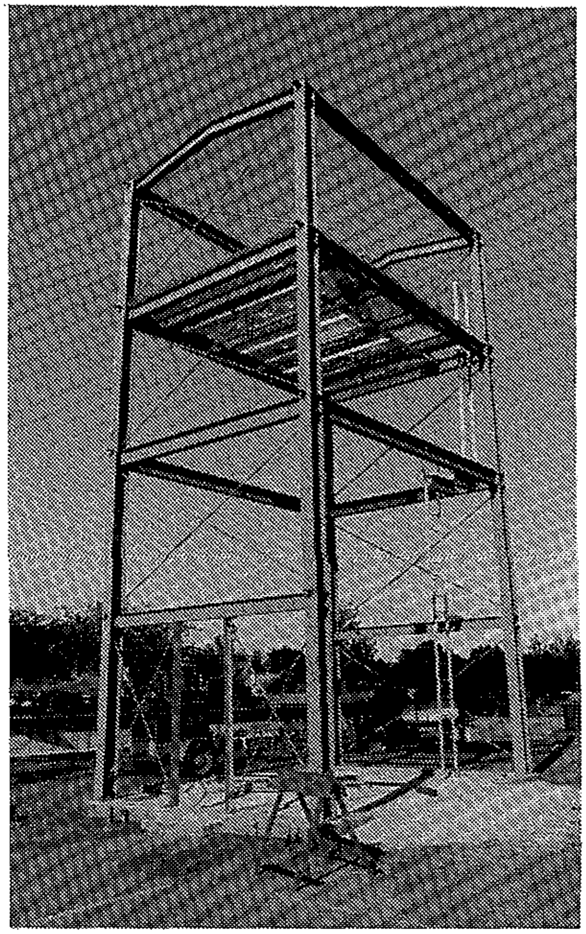
A-1. Simulator foundation slab. The module support frame on surface of slab.



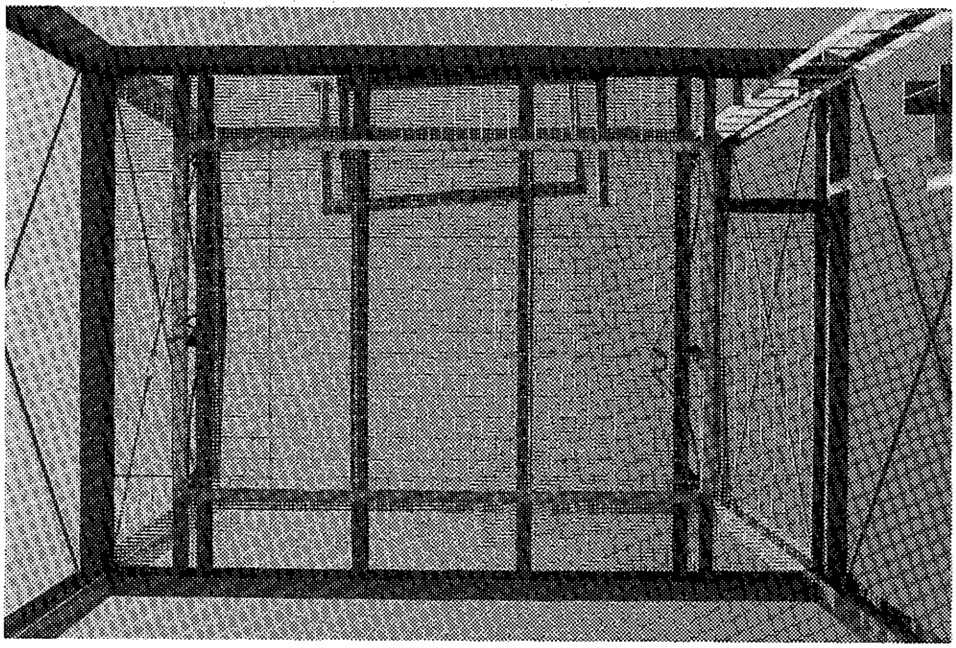
A-2. Frame for one end of structure in place; opposite end member in position for raising.



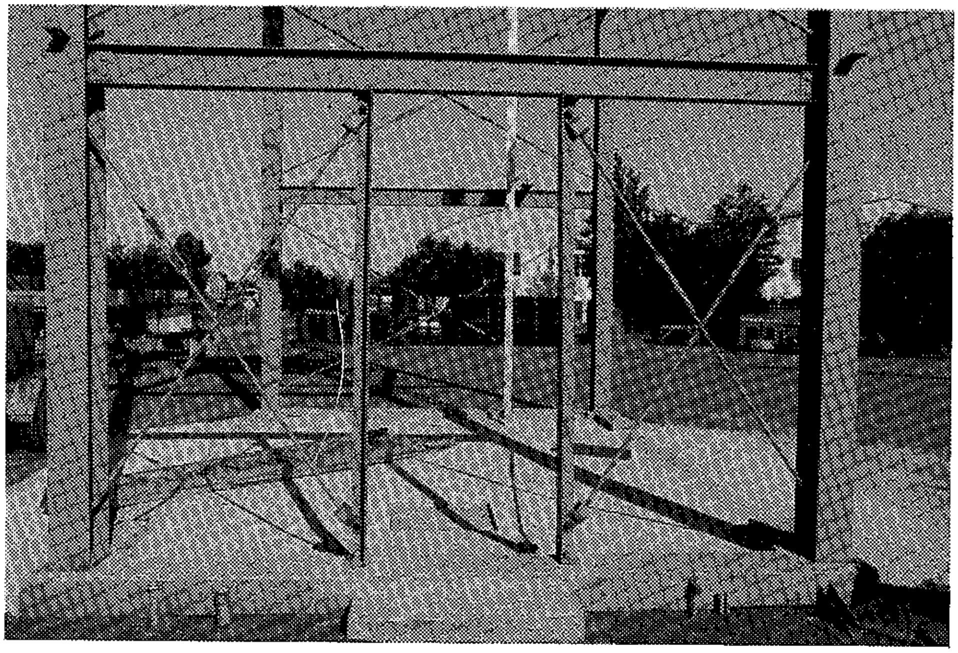
A-3. Finishing the space frame (left).



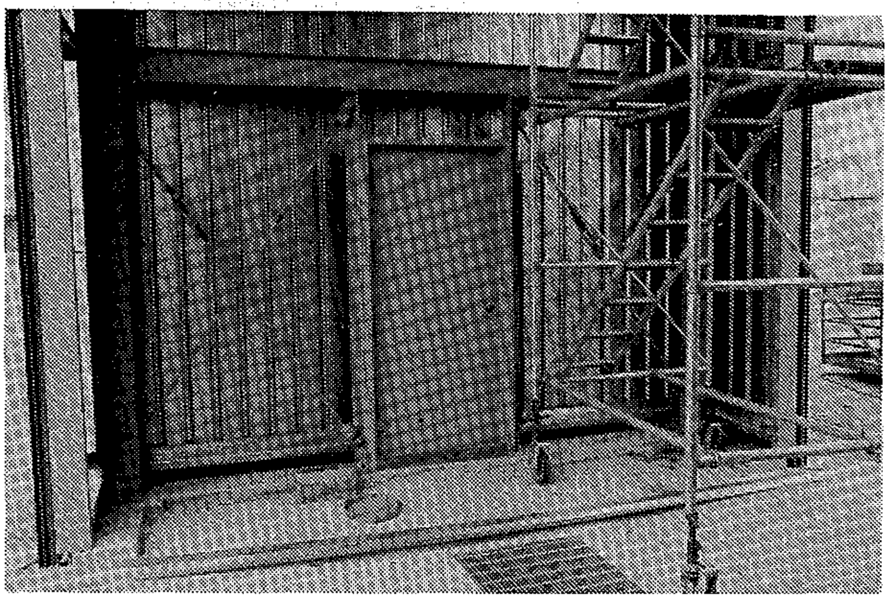
A-4. Completed space frame with top floor grating and module support frame in place.



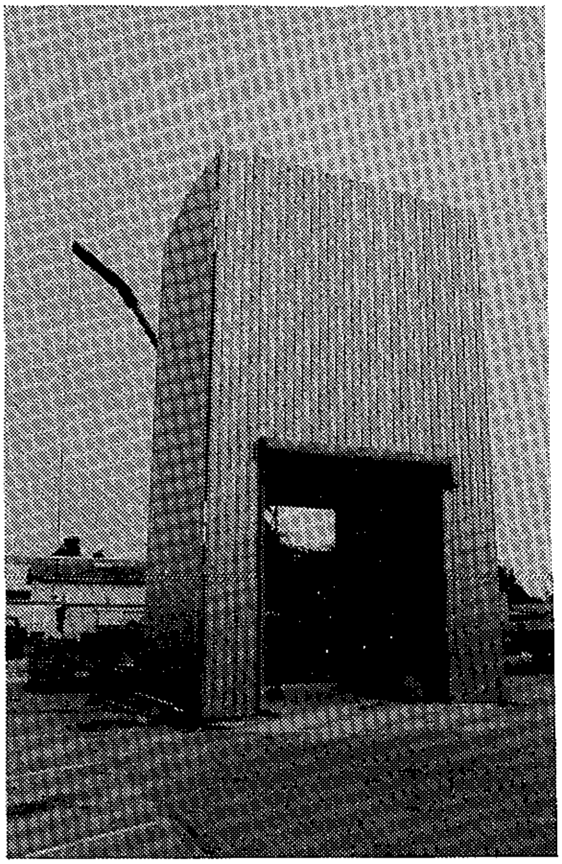
A-5. Looking up at module support frame and top floor grating.



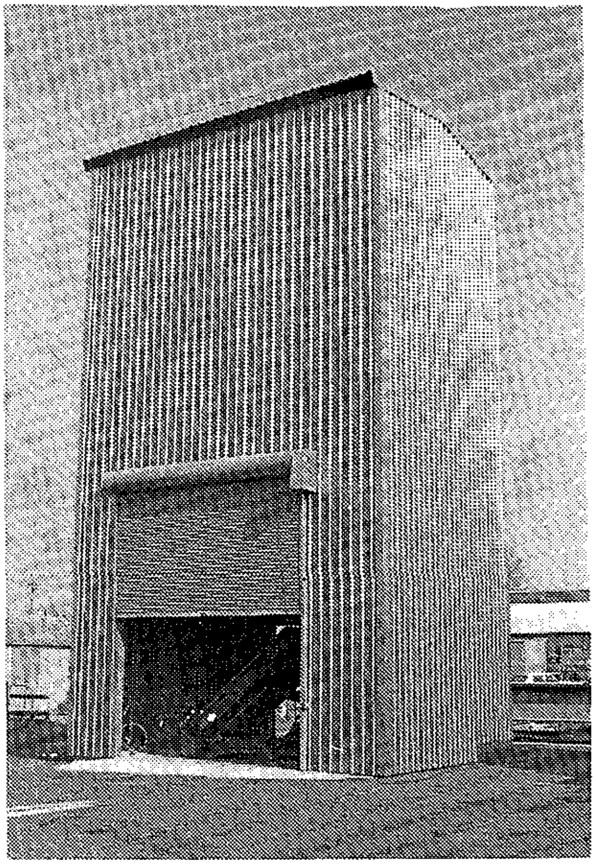
A-6. Bottom portion of space frame.



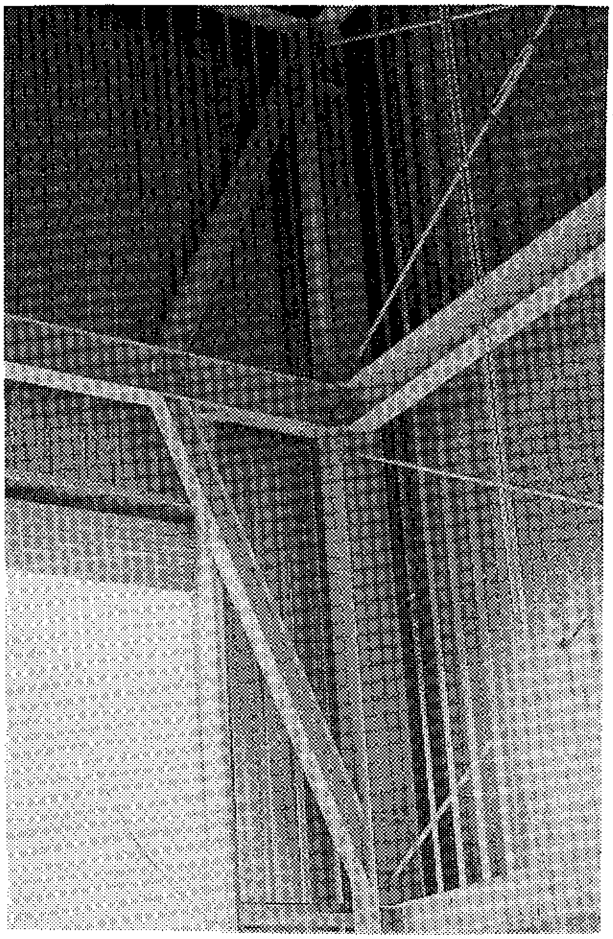
A-7. Access door and siding in place, from the inside.



A-8. Galvanized siding is completed; ready for roof.

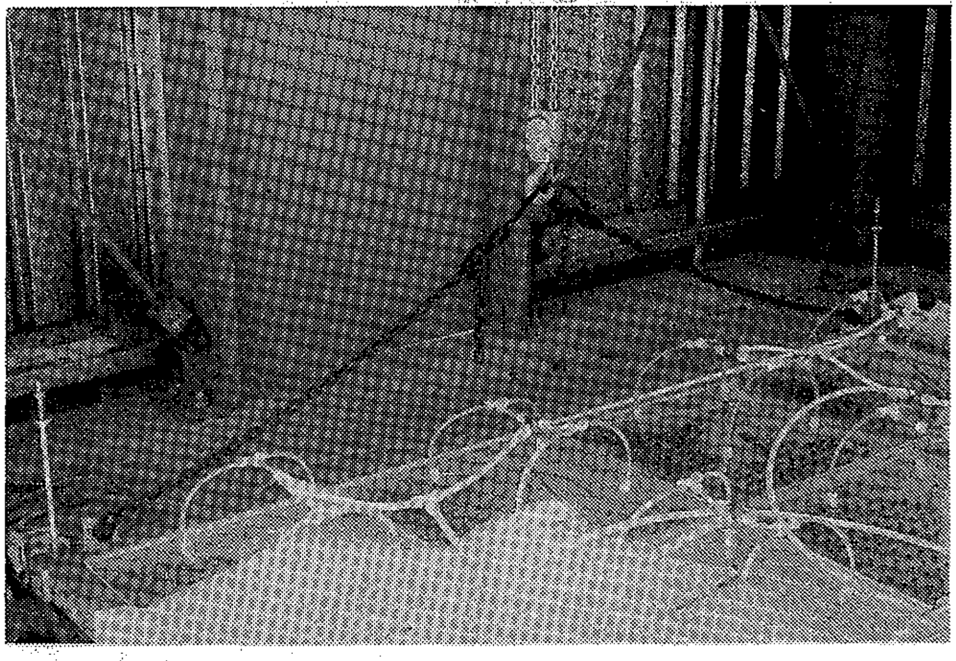


A-9. With roof on and roll-up doors installed, structure is ready for operations.

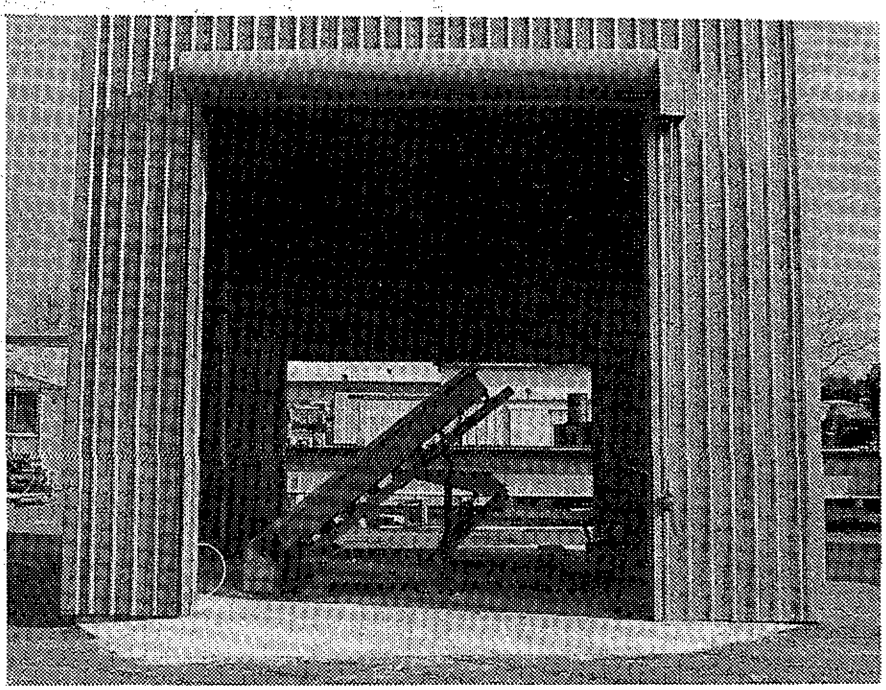


A-10. Interior view, note knee braces added to improve rigidity.

A-11. Ladders and landing provide access to upper floor.



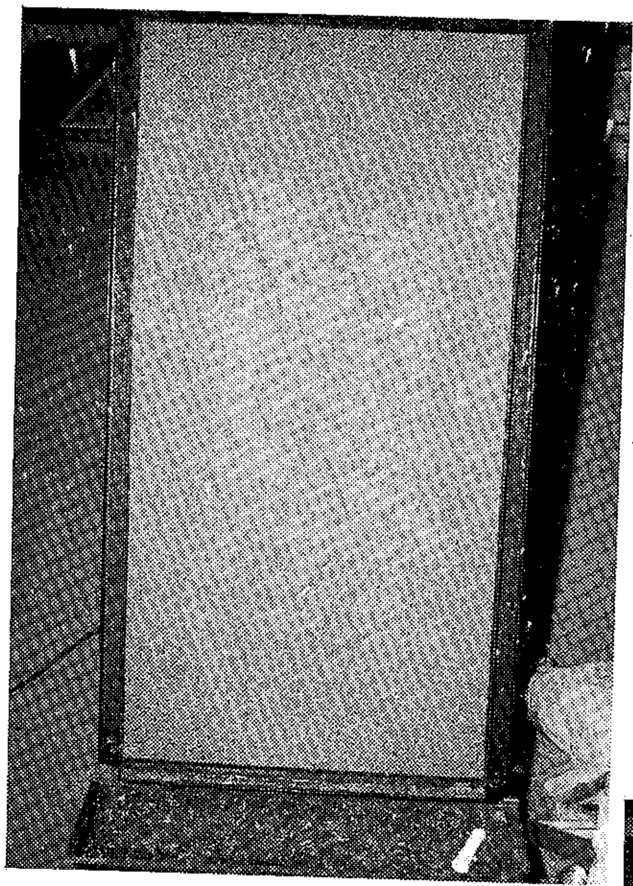
A-12. Attachment of the electric lift to the module support frame.



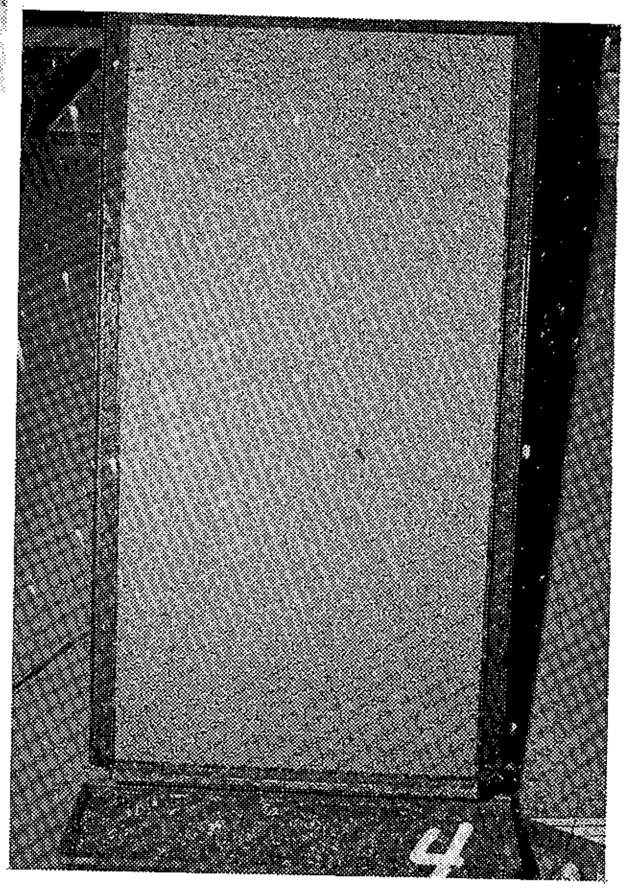
A-13. Sample in place, ready for testing.

APPENDIX B

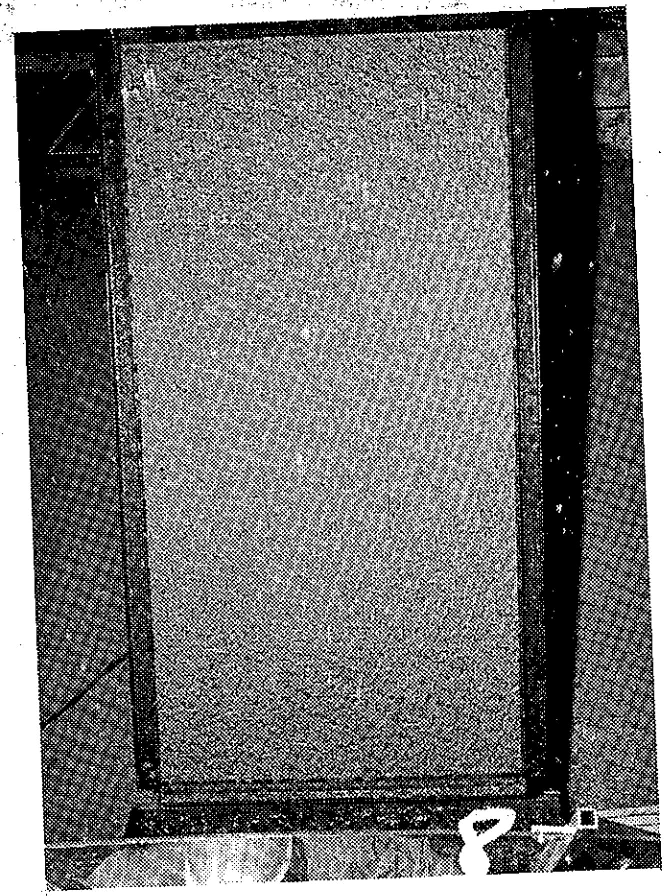
Time Lapse Photographs
of Erosion Produced by the Simulator



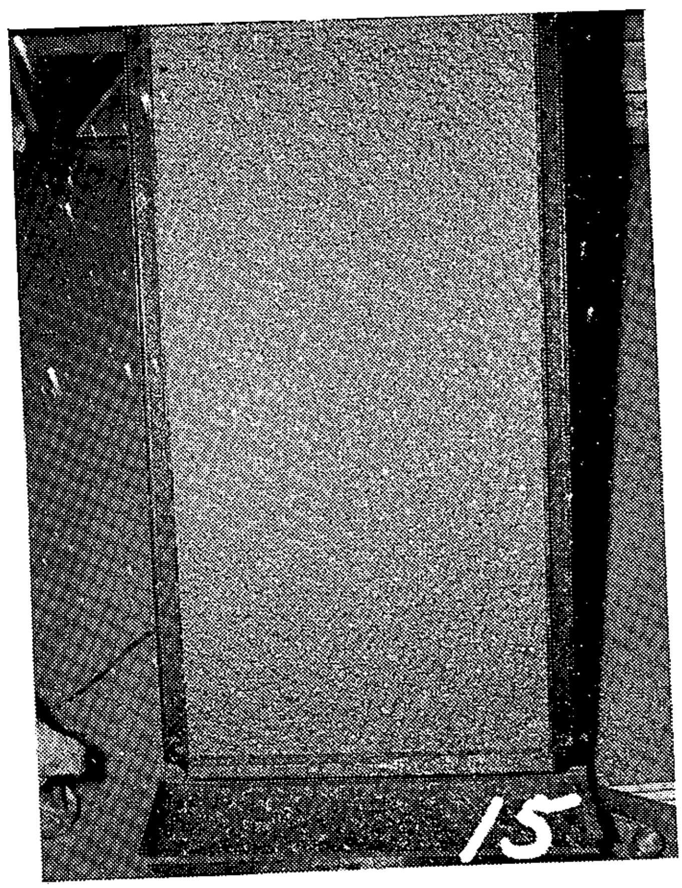
B-1 (left). Initial wetting of untreated sample. Time: 10 sec.



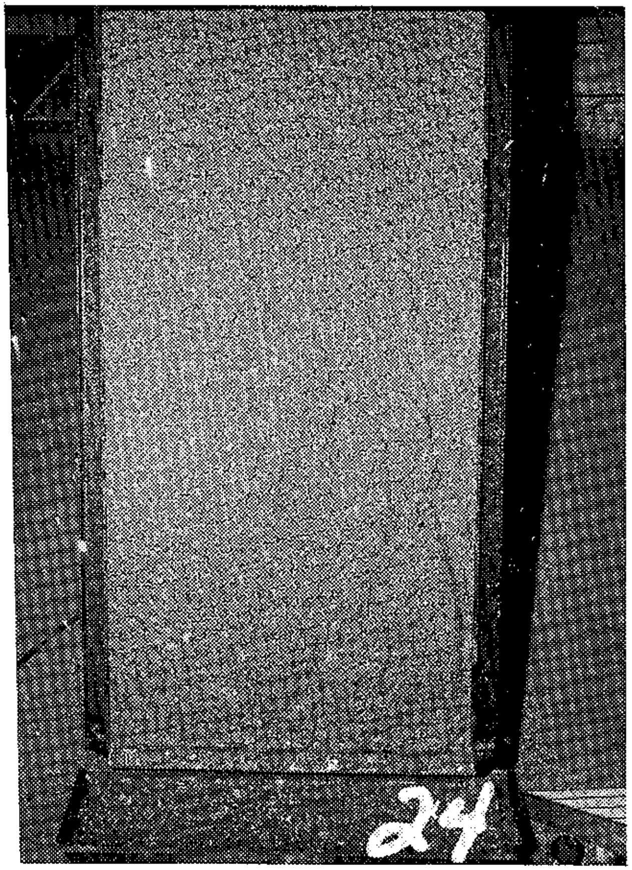
B-2. Entire surface of sample is wetted. Sheet erosion is commencing at top of sample. Time: 40 sec.



B-3 (left). Localized surface saturation occurring. Sheet erosion has started near the top of sample. Time: 80 sec.

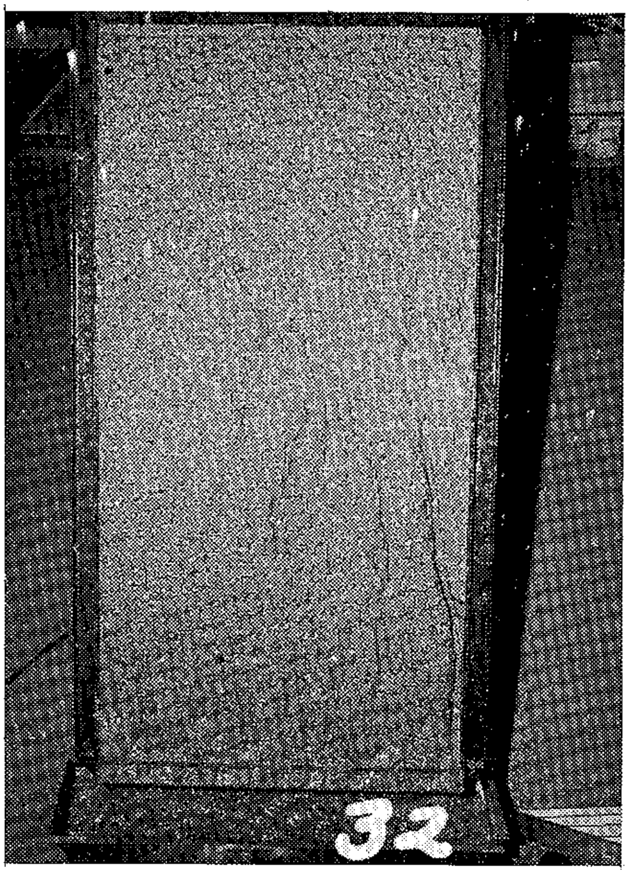


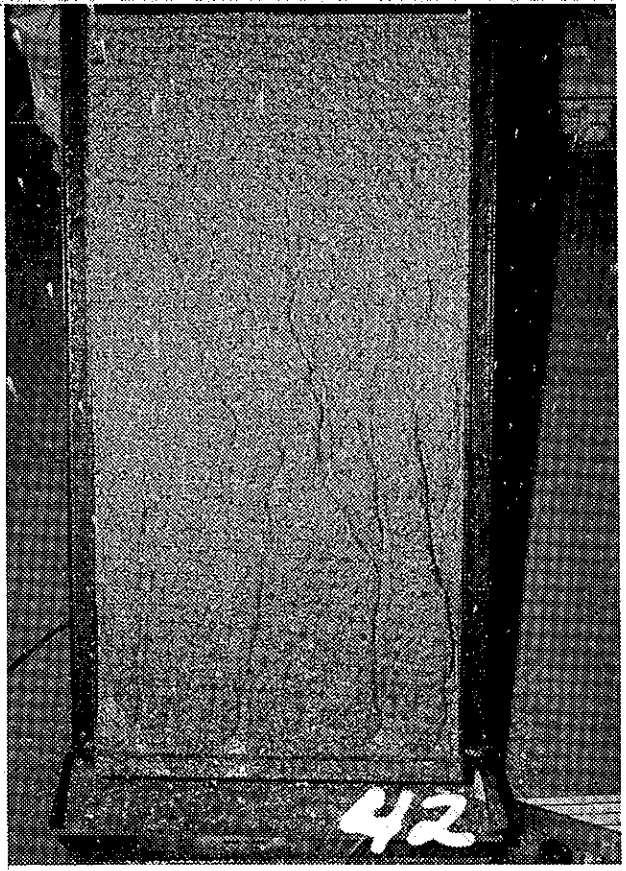
B-4. Entire sample surface is saturated. Rilling has begun in bottom right corner. This would constitute failure, as discussed in the text. Time: 150 sec.



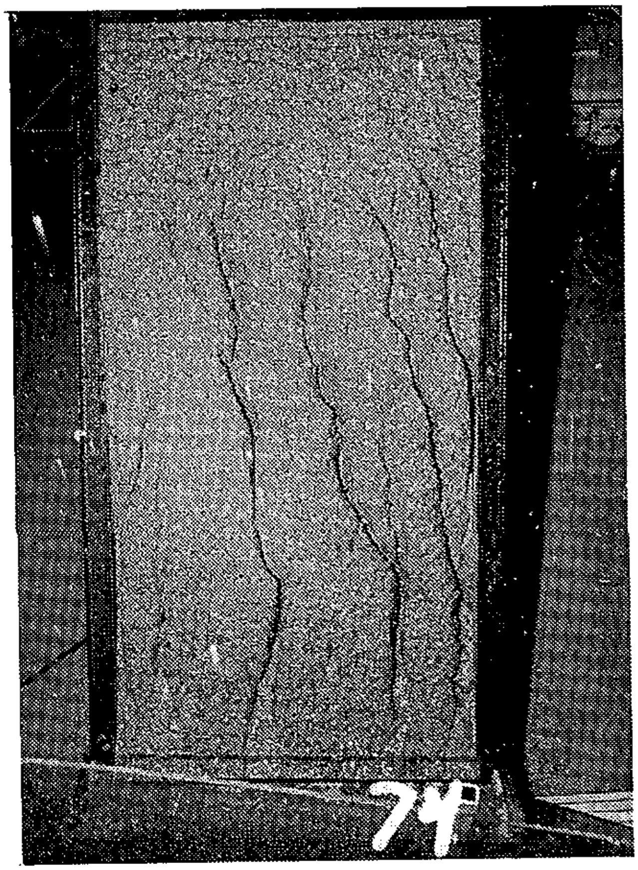
B-5 (left). Rill progression up-slope. Note edge effect in lower right sector. Time: 240 sec.

B-6. Rilling in lower right 2/3 of sample is very obvious. Time: 320 sec.

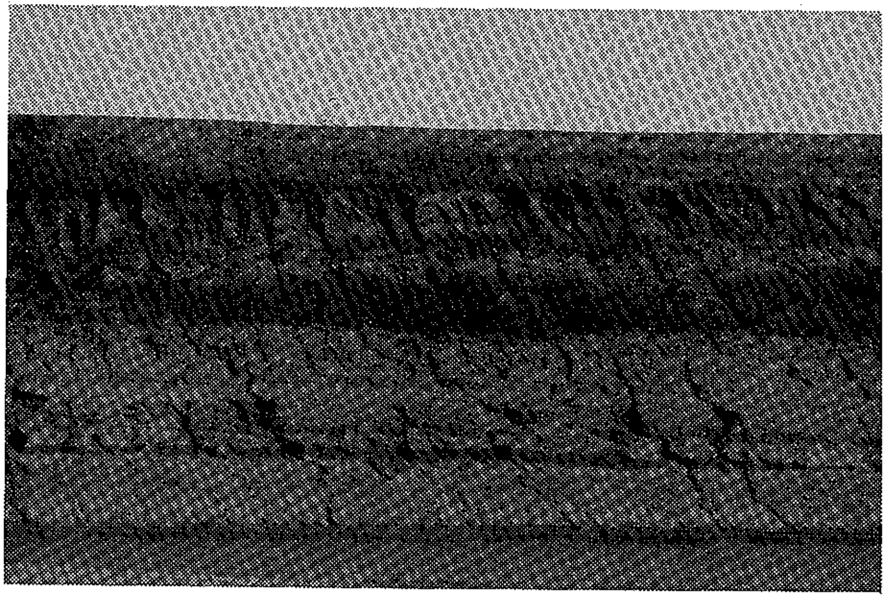




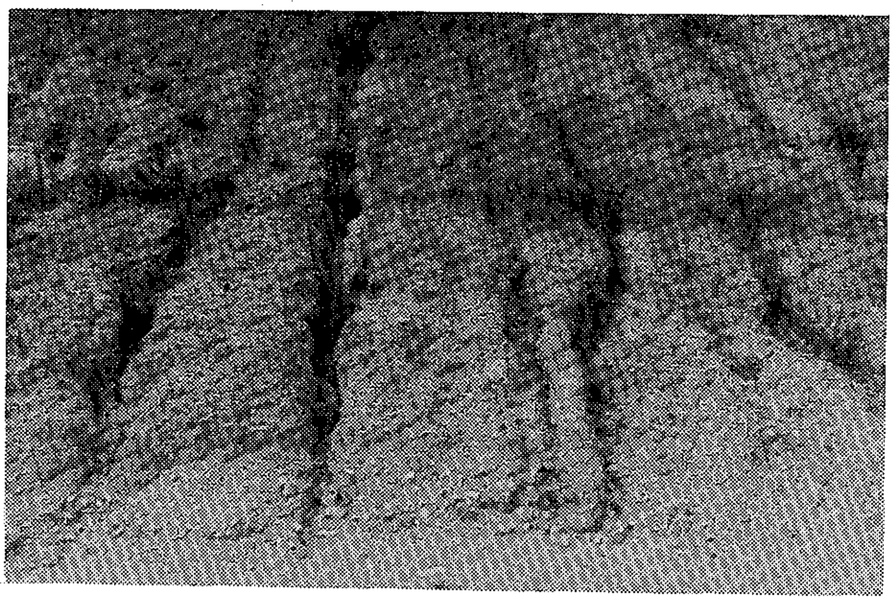
B-7 (left). Rilling is progressing up-slope and deepening. Time: 420 sec.



B-8. Rills at termination of exposure (740 seconds). Irreparable damage has occurred. In the field, such damage would require regrading to arrest erosion and prevent serious failure.



B-9. Typical rill erosion on a highway cut slope near Davis, California.



B-10. Detail view of rills changing to gullies.